UNIVERSITY OF DELAWARE
CENTER FOR COMPOSITE MATERIALS
INTERNATIONALLY RECOGNIZED EXCELLENCE

SIMULATIONS FOR DESIGN, SENSING AND CONTROL OF LIQUID COMPOSITE MOLDING PROCESSES

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UD-CCM and UD-ME

Research Funded by Advanced Material Intelligent Processing Center
Established at University of Delaware by Office of Naval Research

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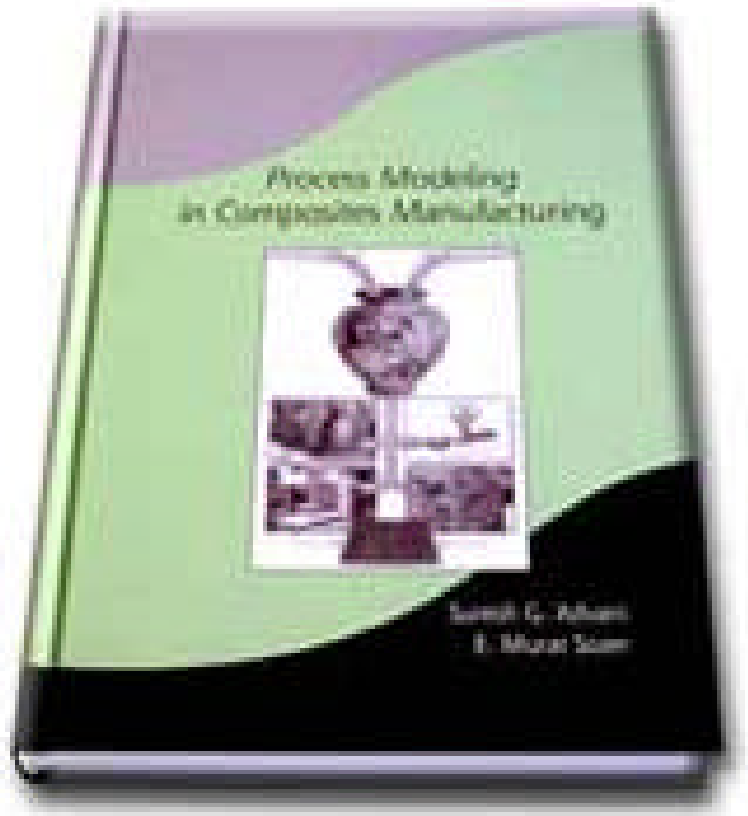
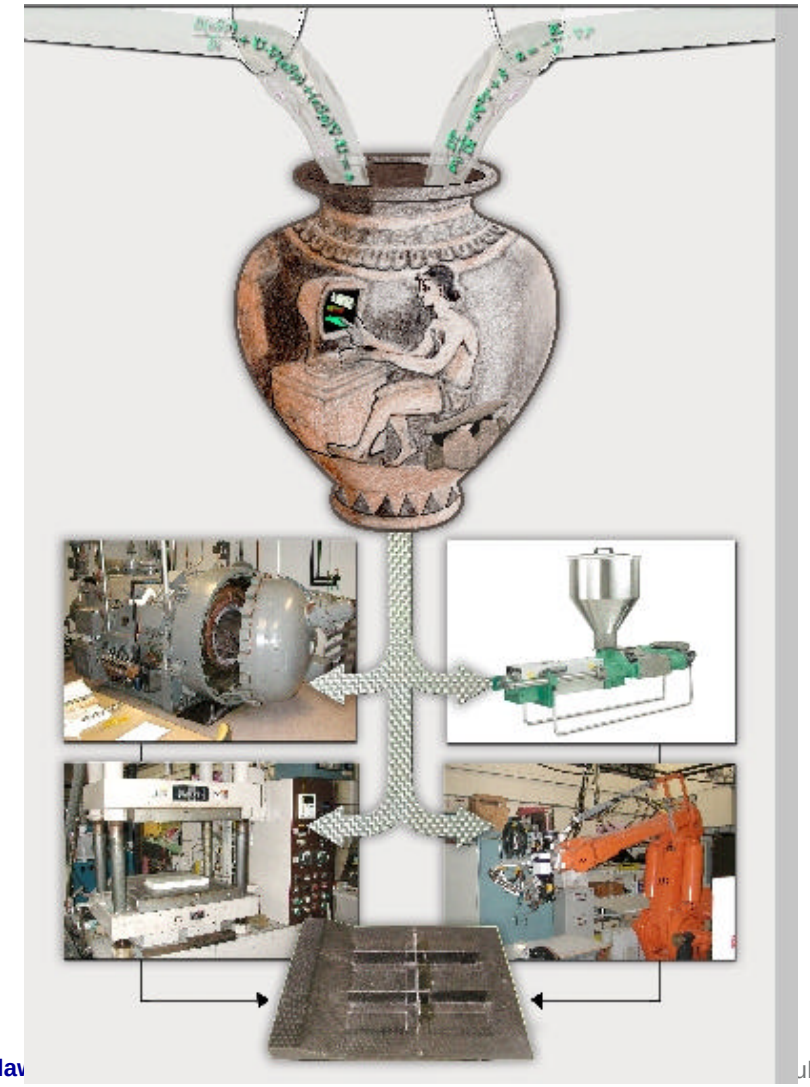
Composite Process Modeling in a Text Book





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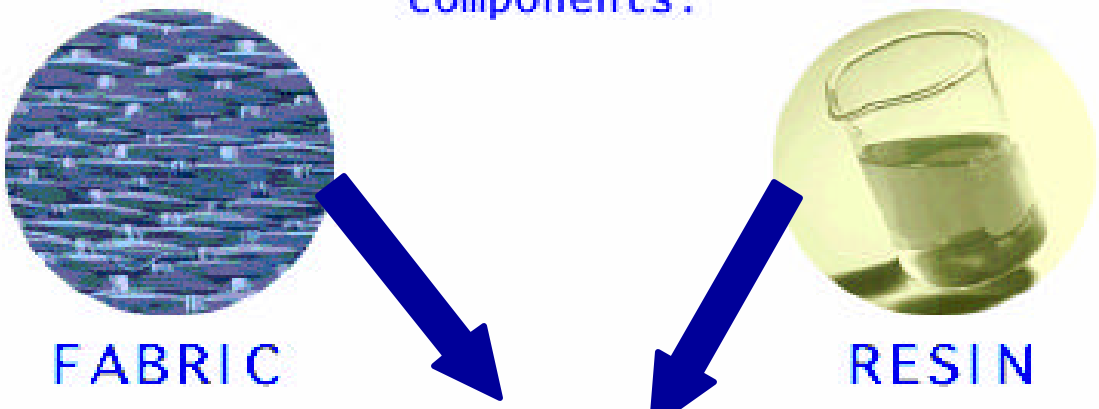
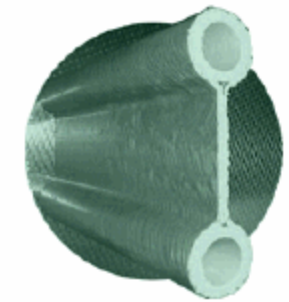
What Are Composites?

Composites are comprised of two or more seperate materials that, when combined, lead to improved properties over the individual components.





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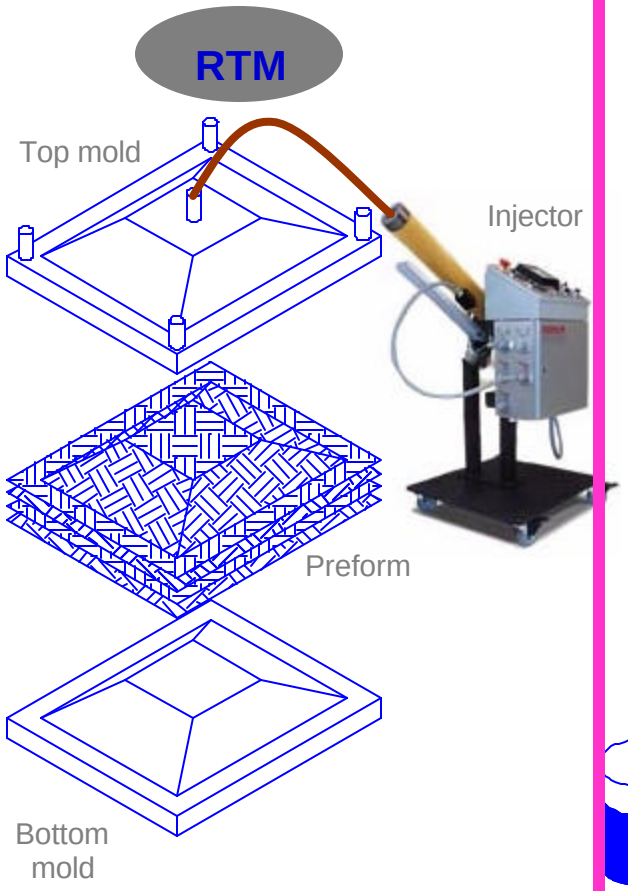
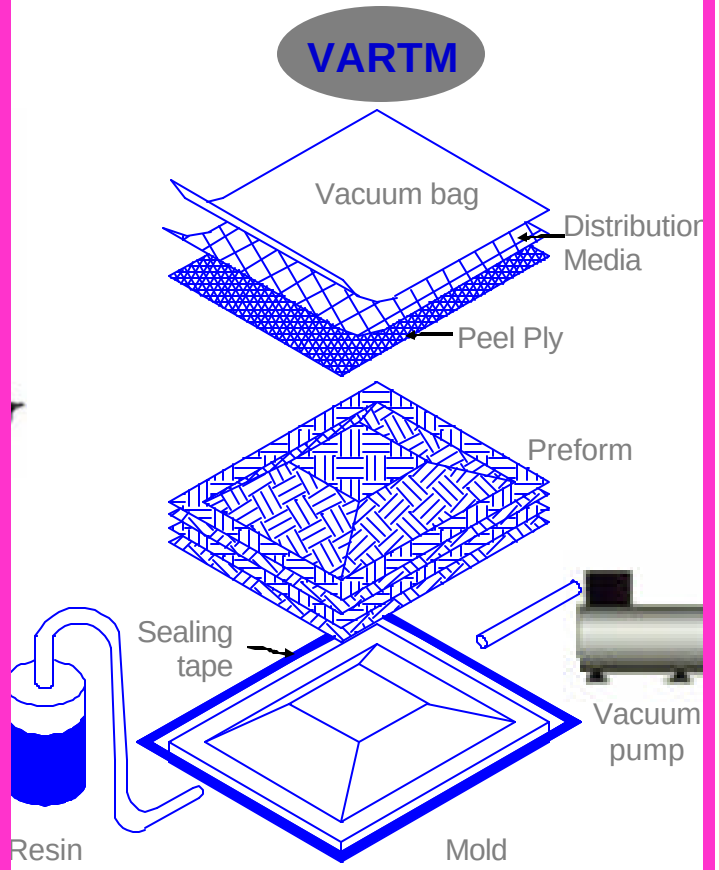
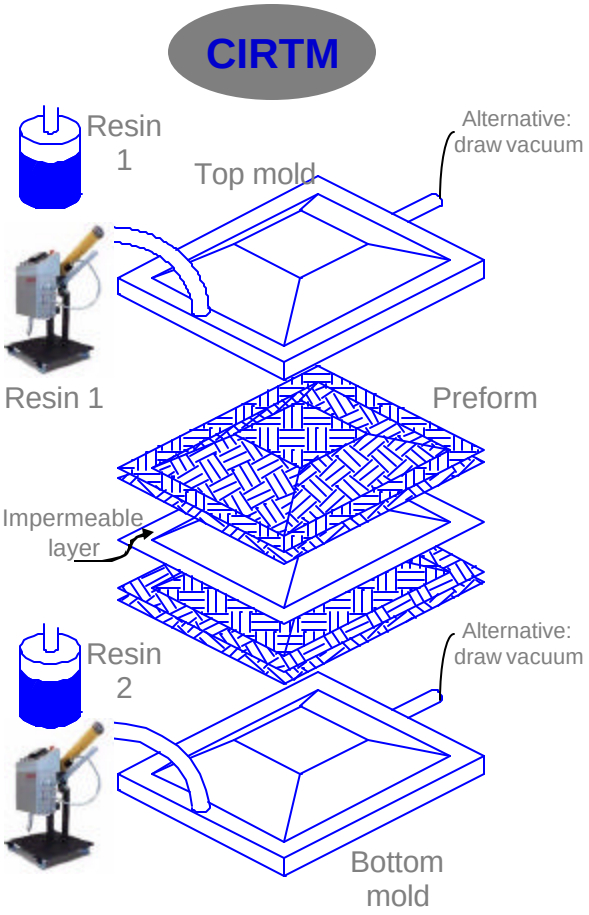
Liquid Composite Molding Processes







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Applications

Automobiles

Infrastructure

Aircraft

Marine Systems

Bicycles

Mass Transit Vehicles

Cargo Containers

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Issues and Challenges in Liquid Molding

Issues

- Complete Saturation and Voids
- Injection and Vent Locations
- Process Control
- Reliability and Repeatability

Challenges

- Three Dimensional Flow Modeling
- Saturation Physics
- Dimensional Tolerances
- Flow Control
- Distribution Media Design
- Location of Resin Injectors
- Automation
- Large and Complex Parts

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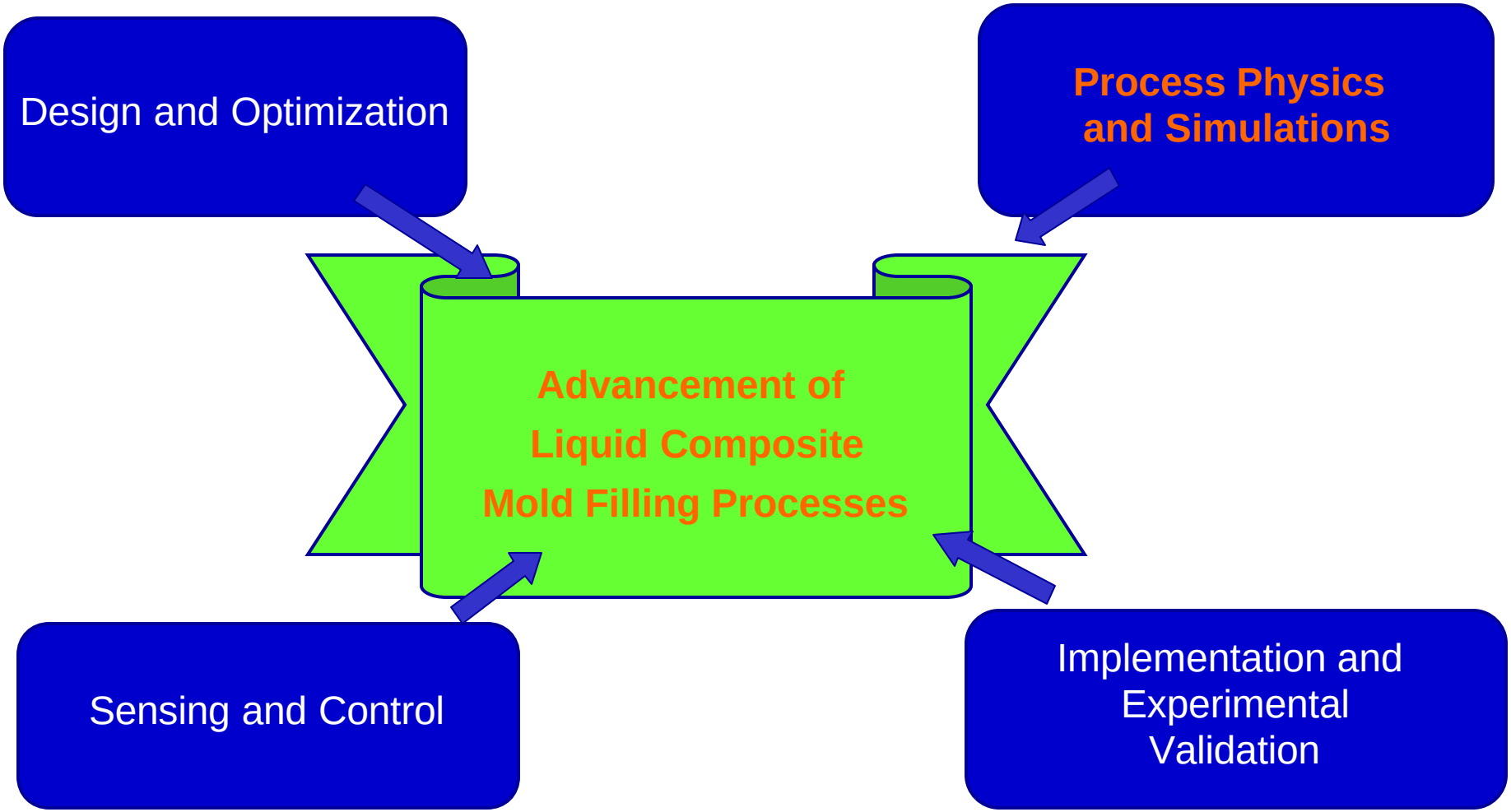
Goal

Develop and Apply Tools in an Intelligent Manner to Advance Manufacturing by Liquid Composite Molding



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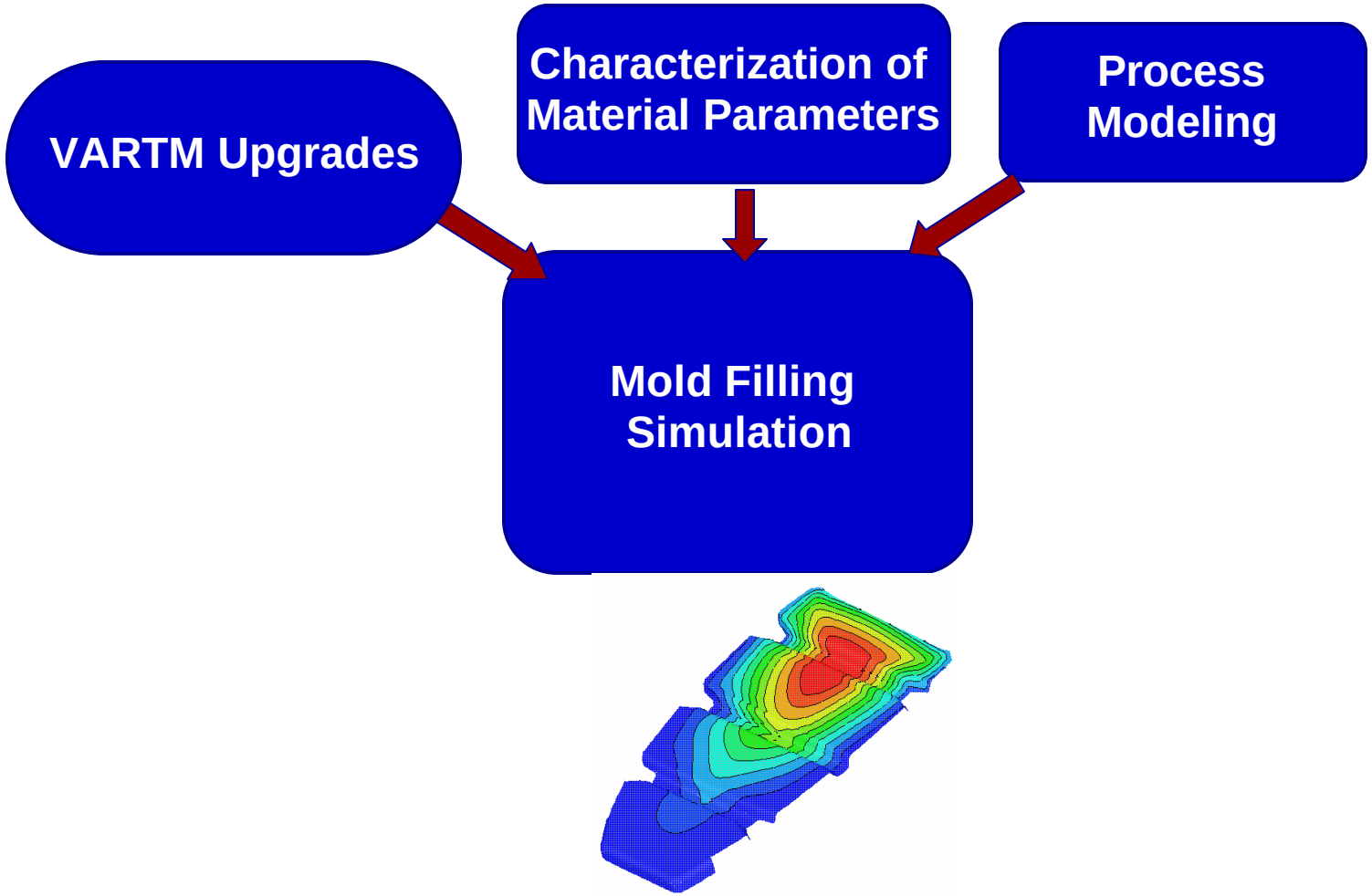
Process Physics and Simulations



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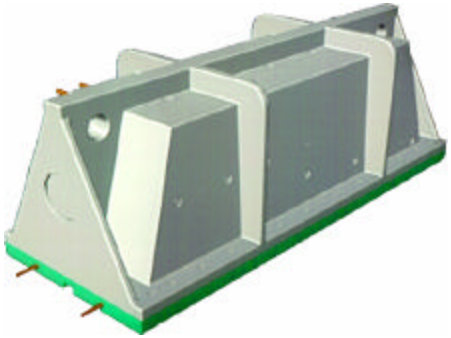
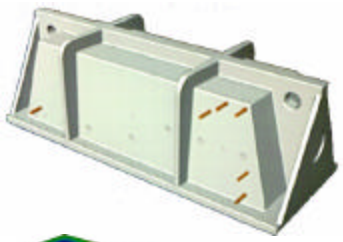
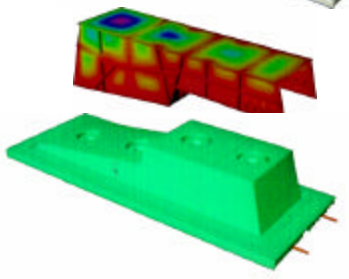
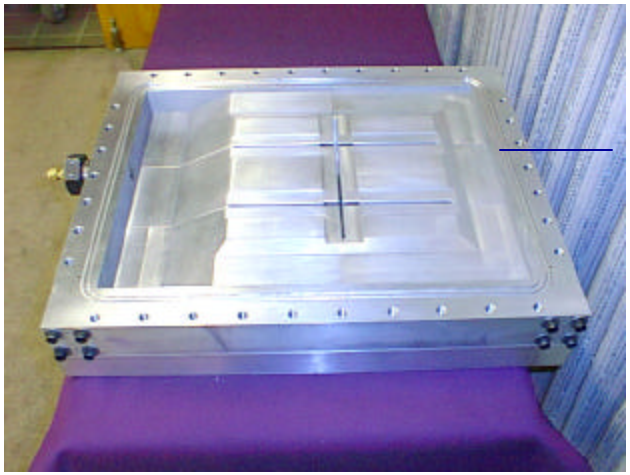
Mold Filling : Need For Simulation

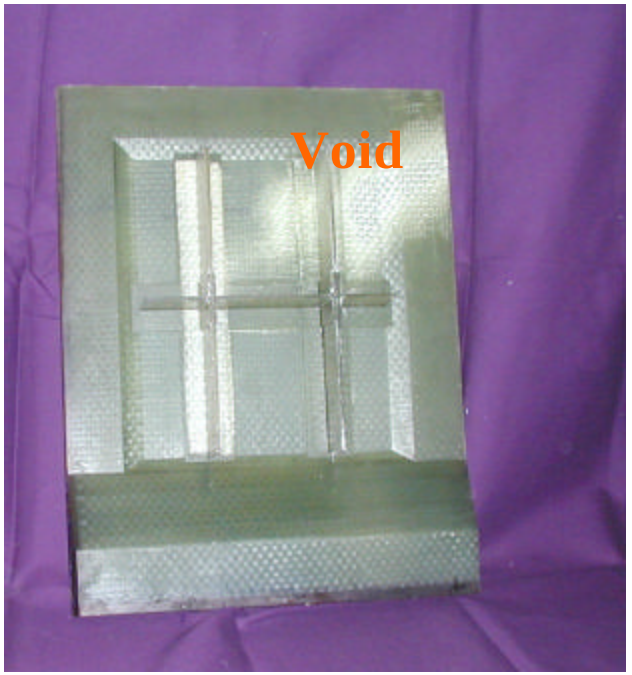


Closed Mold









Void Formation in final part

Mold filling simulations are necessary to examine the resin flow in closed molds

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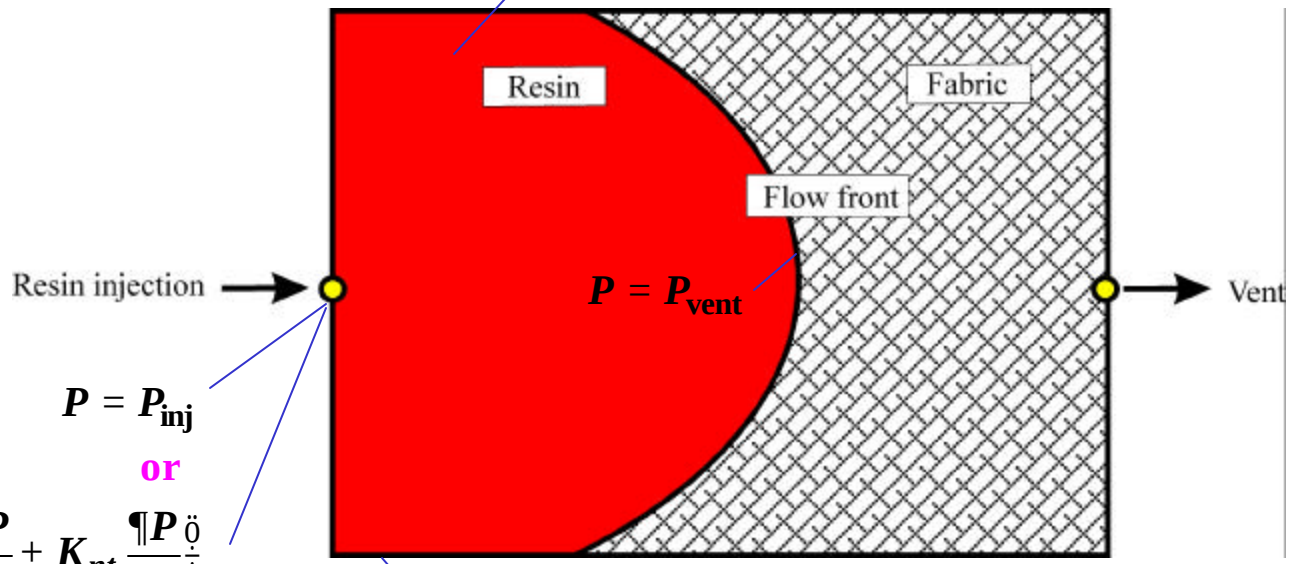
Governing Equations for RTM

2-D Darcy's Law
velocity-pressure relationship:

$$\begin{Bmatrix} \bar{u}_x \\ \bar{u}_y \end{Bmatrix} = -\frac{1}{h}\begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix}\begin{Bmatrix} \partial P/\partial x \\ \partial P/\partial y \end{Bmatrix}$$

$$\frac{\partial}{\partial x}\left(\frac{K_{xx}}{h}\frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial x}\left(\frac{K_{xy}}{h}\frac{\partial P}{\partial y}\right) + \frac{\partial}{\partial y}\left(\frac{K_{yx}}{h}\frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{K_{yy}}{h}\frac{\partial P}{\partial y}\right) = 0$$



$$P = P_{inj}$$

or

$$Q_{inj} = -\frac{hL}{h}\left(K_{nn}\frac{\partial P}{\partial n} + K_{nt}\frac{\partial P}{\partial t}\right)$$

$$v_n = -\frac{1}{h}\left(K_{nn}\frac{\partial P}{\partial n} + K_{nt}\frac{\partial P}{\partial t}\right) = 0$$

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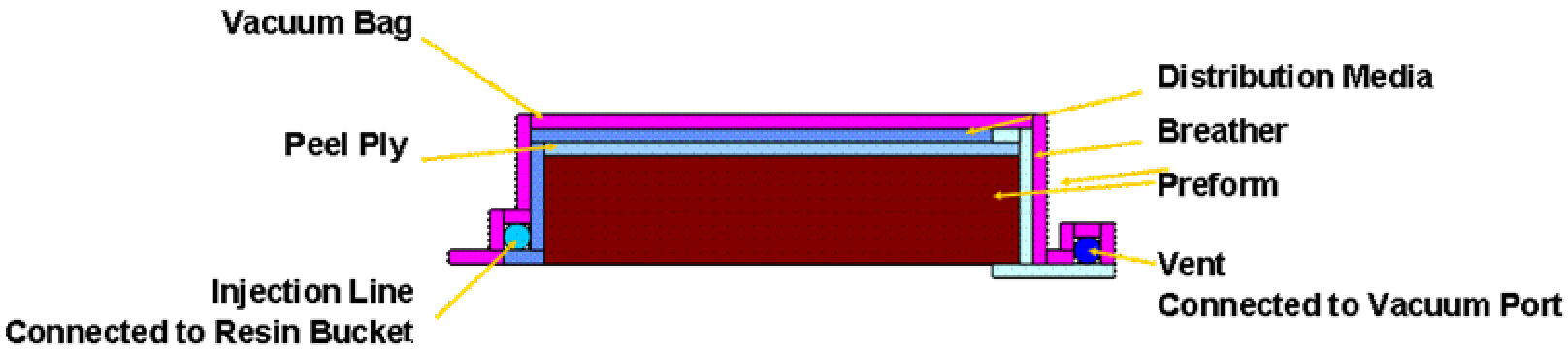
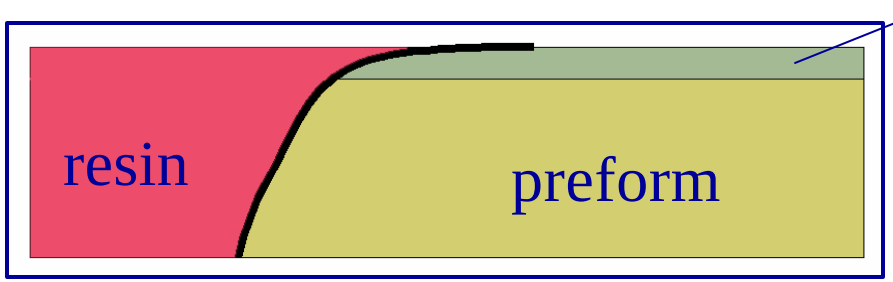
3D Flow in VARTM





3-D Darcy's Law

velocity-pressure relationship:

$$\begin{Bmatrix} \overline{u}_x \\ \overline{u}_y \\ \overline{u}_z \end{Bmatrix} = -\frac{1}{h} \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{bmatrix} \begin{Bmatrix} \partial P/\partial x \\ \partial P/\partial y \\ \partial P/\partial y \end{Bmatrix}$$

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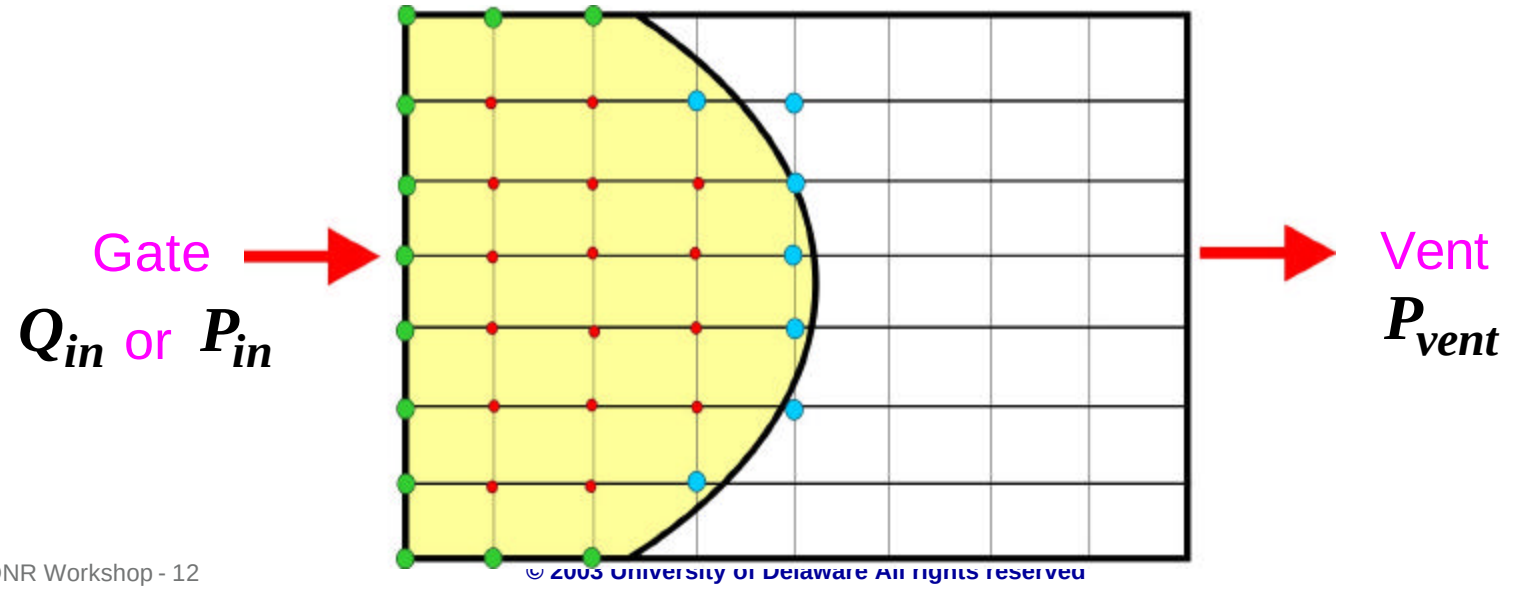
Finite Element Method for the Solution of Resin Pressure

$$P^e = \sum_{i=1}^{n} N_i P_i \qquad [[S^e]][P] = [\cancel{0}]\ Q_{bc}$$

$$S_{ij}^e = \int_W \left(\frac{K_{xx}}{h} \frac{\partial N_j}{\partial x} \frac{\partial N_i}{\partial x} + \frac{K_{yy}}{h} \frac{\partial N_j}{\partial y} \frac{\partial N_i}{\partial y} + \frac{K_{xy}}{h} \frac{\partial N_j}{\partial x} \frac{\partial N_i}{\partial y} + \frac{K_{xy}}{h} \frac{\partial N_j}{\partial y} \frac{\partial N_i}{\partial x} \right) dW$$



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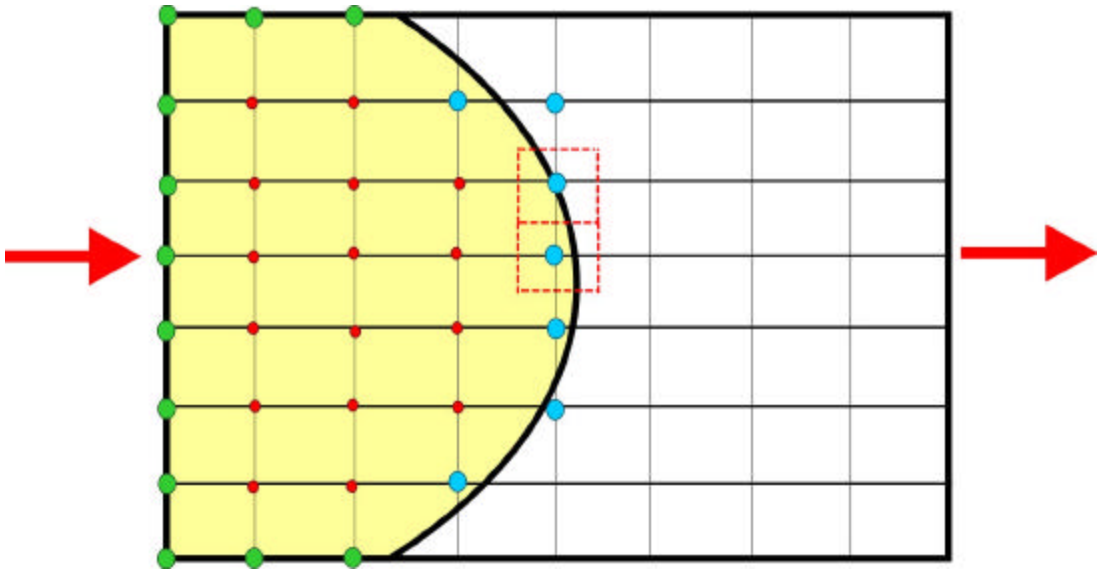
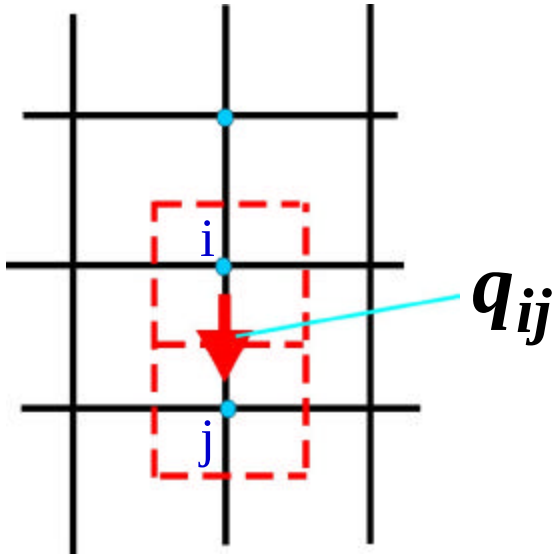
Control Volume Approach for the Advancement of the Flow Front





$$Q_i = \sum_{j=1}^{n} q_{ij} \, \Delta t$$

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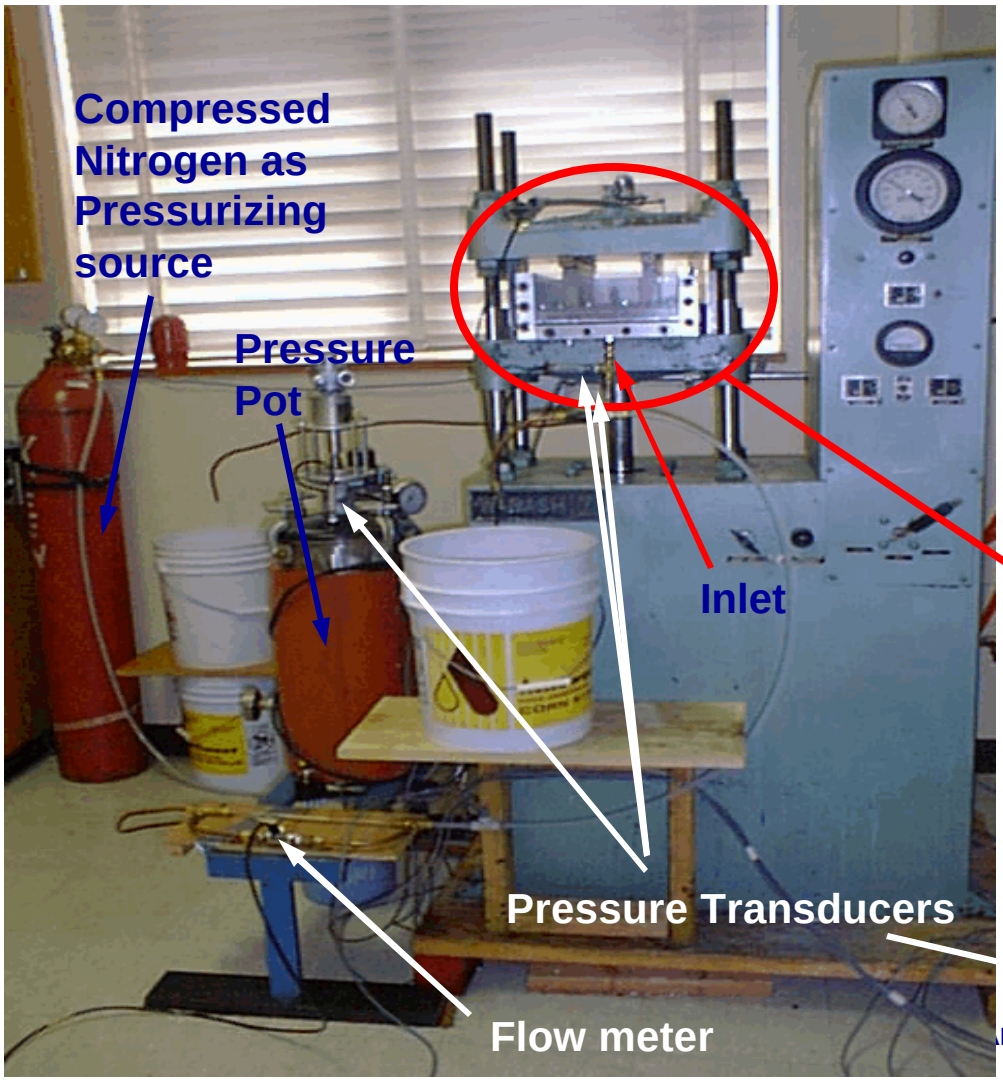
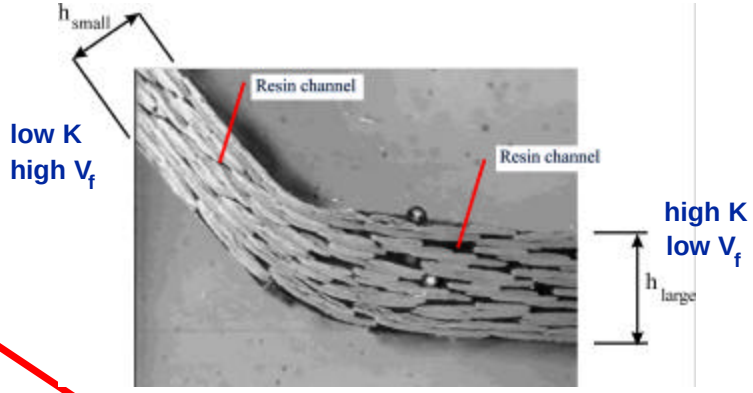
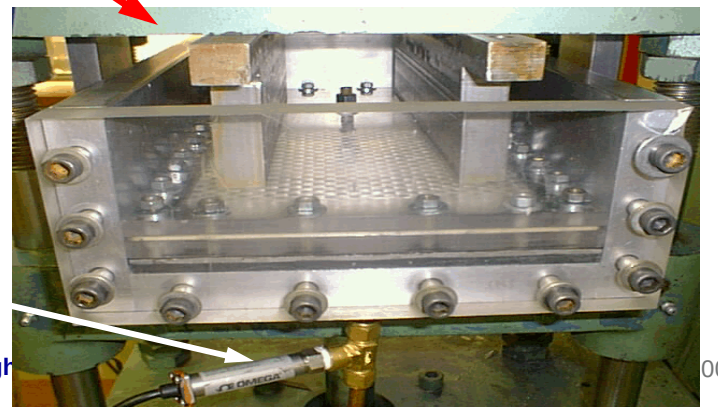
Permeability Measurements for RTM



Detailed measurements of permeability vs. V_f by changing the compaction load





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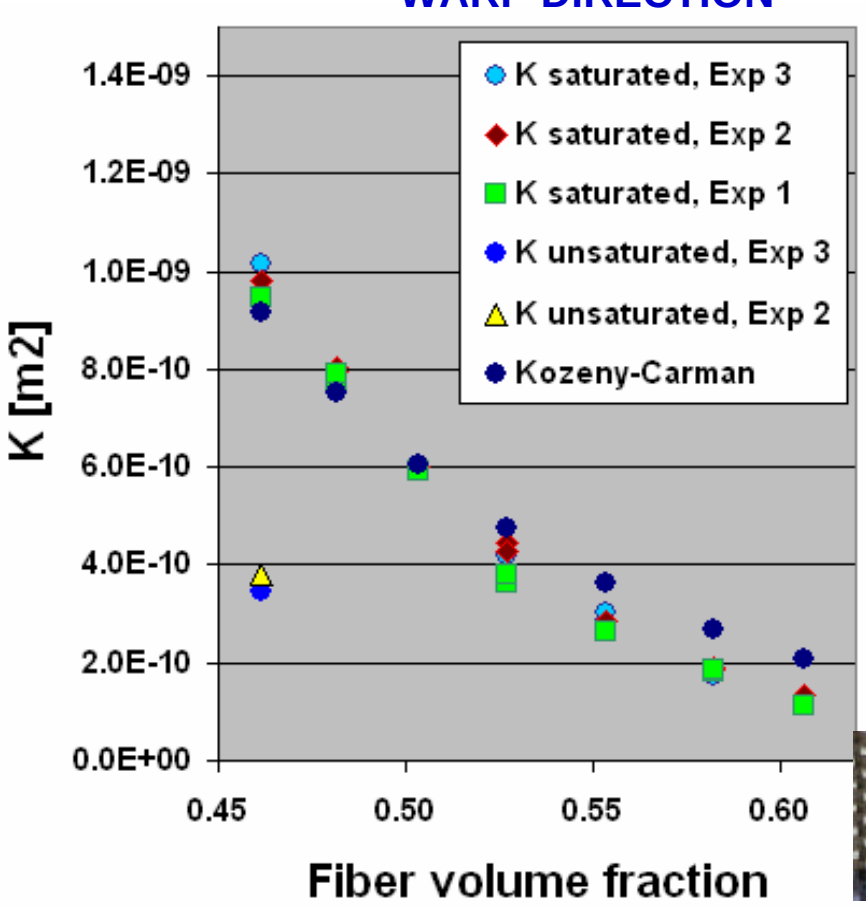
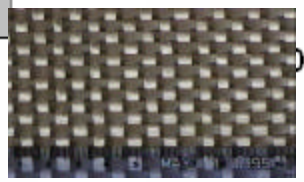
Permeability as a Function of Fiber Volume Fraction

Fabric = Vetrotex 324, 14 layer.

WARP DIRECTION





WEFT DIRECTION

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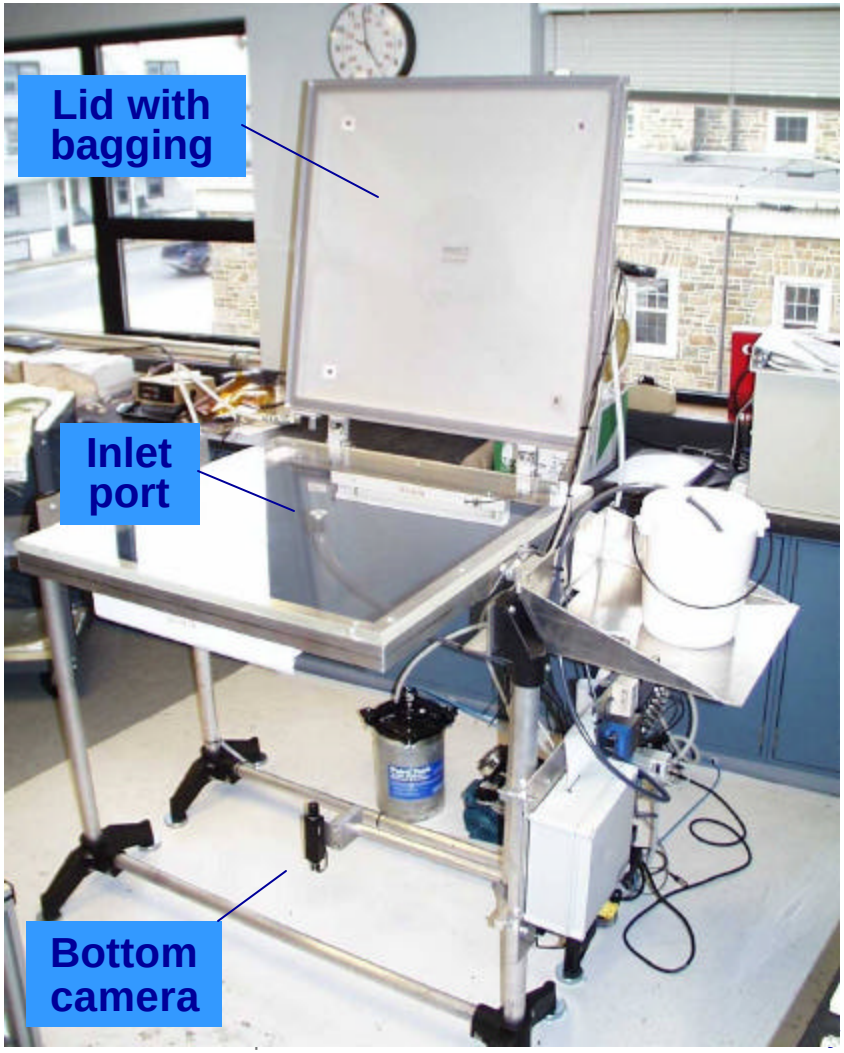
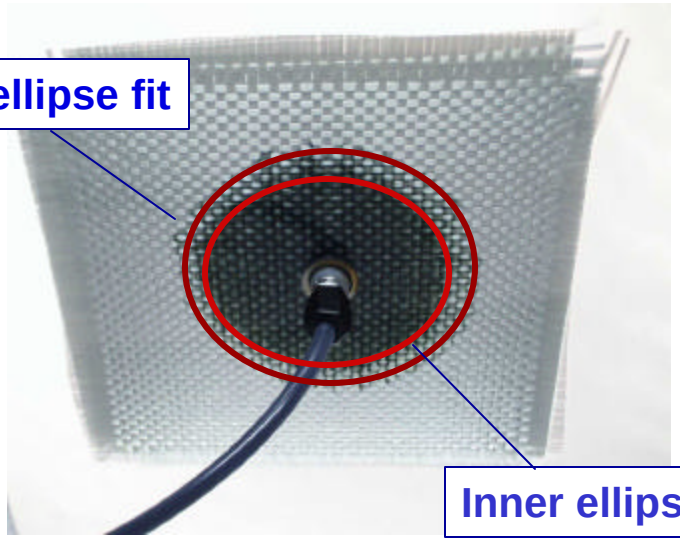
PERMSTAT Permeability Measurement Station for VARTM Process





Top: Bottom view of point injection into dry preform, with blackened corn syrup

Left: PERMSTAT set-up

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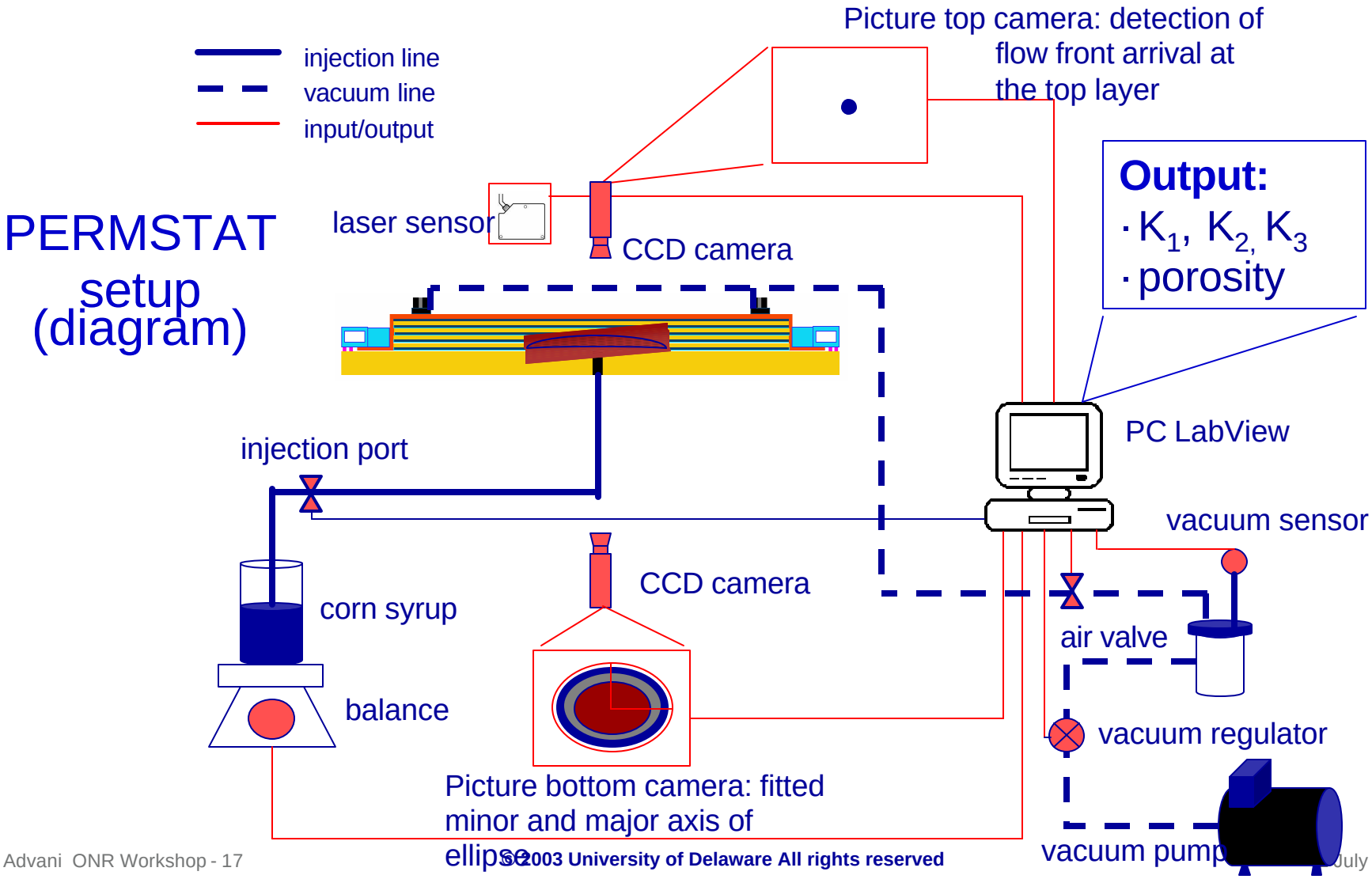
PERMSTAT Schematic



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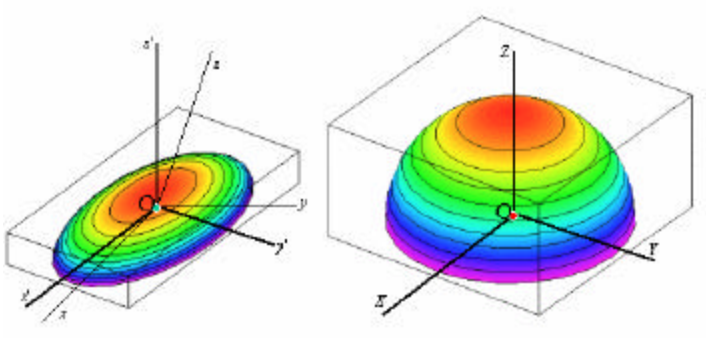
3-D Permeability Estimation Approach

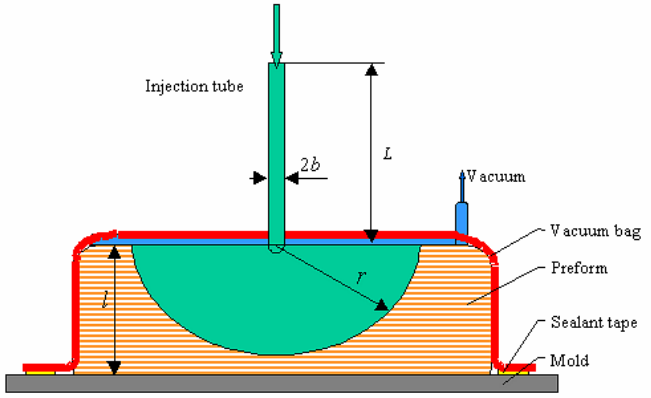
Mass of the liquid that is in the perform and the injection tube (not required)

Coordinates of the flow front position on the principal axes, i.e the major axes of the ellipse.

Time elapsed from the start of injection

PERMEABILITY TENSOR
K_{xx}, K_{yy}, K_{zz}.





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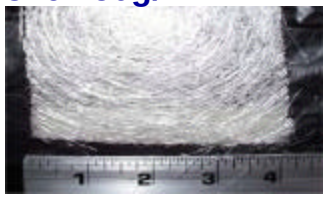
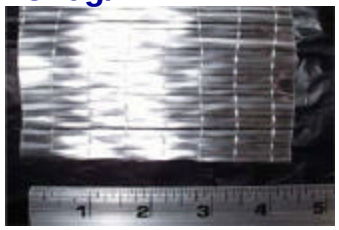
Principal Permeability Values for Typical Preforms

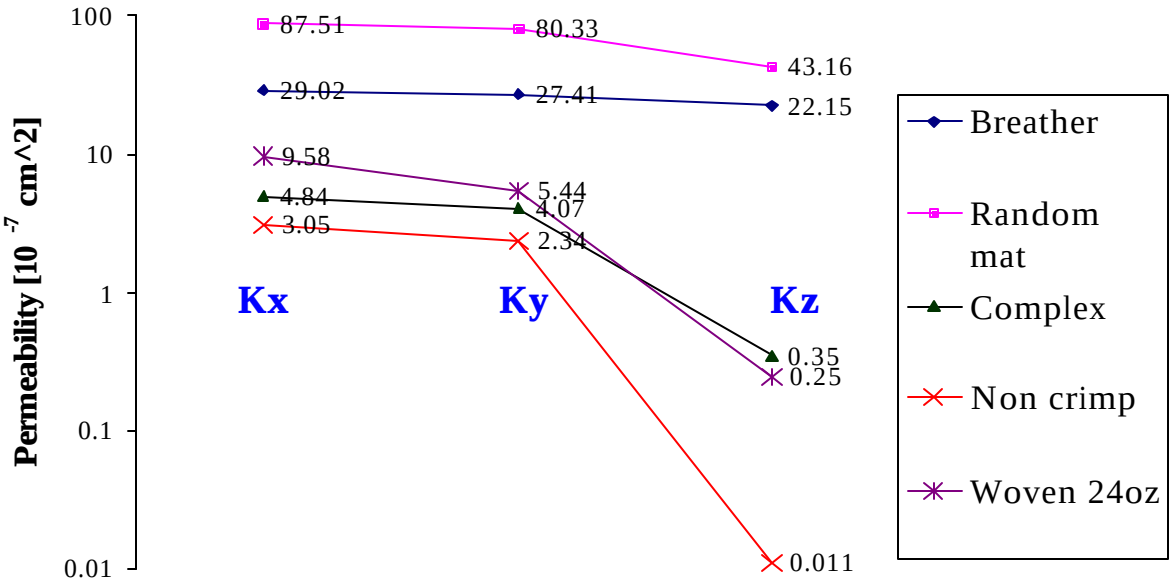
Breather:
Airtech Airweave N10 400g/m²

Random mat:
Vetrotex Unifilio 816 450g/m²

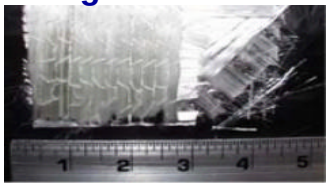


Non crimp : 320g/m²

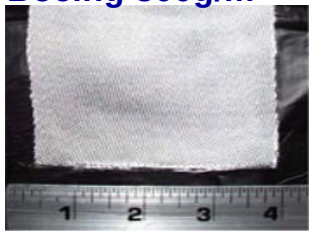




Complex:
Vetrotex Stitchment 2400g/m²



Woven:
Boeing 300g/m²



Woven:
Vetrotex 324 800g/m²

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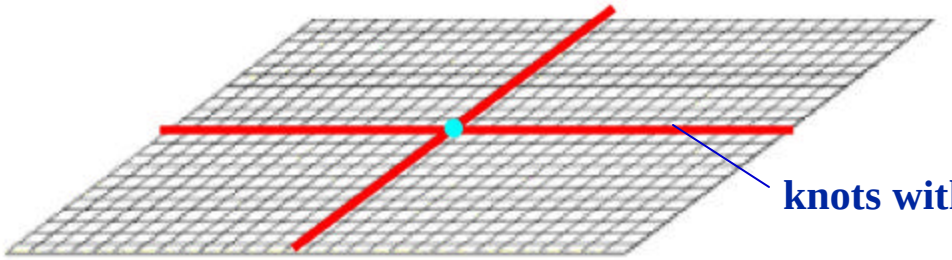
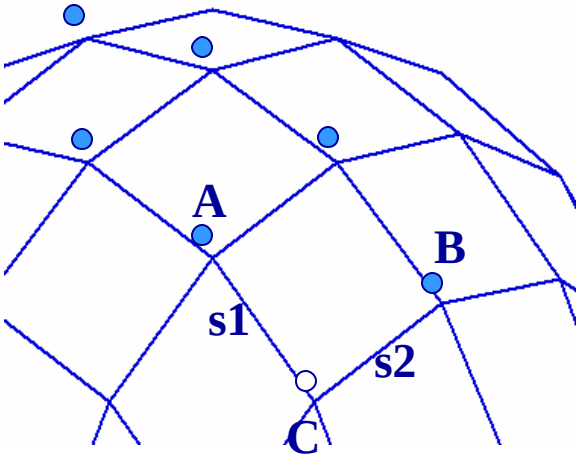
Principal Direction and Vf Change for Double Curvatures in Part Geometry



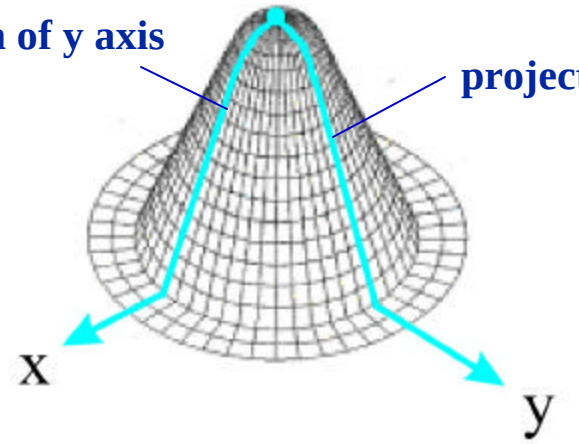
knots with b.c.'s

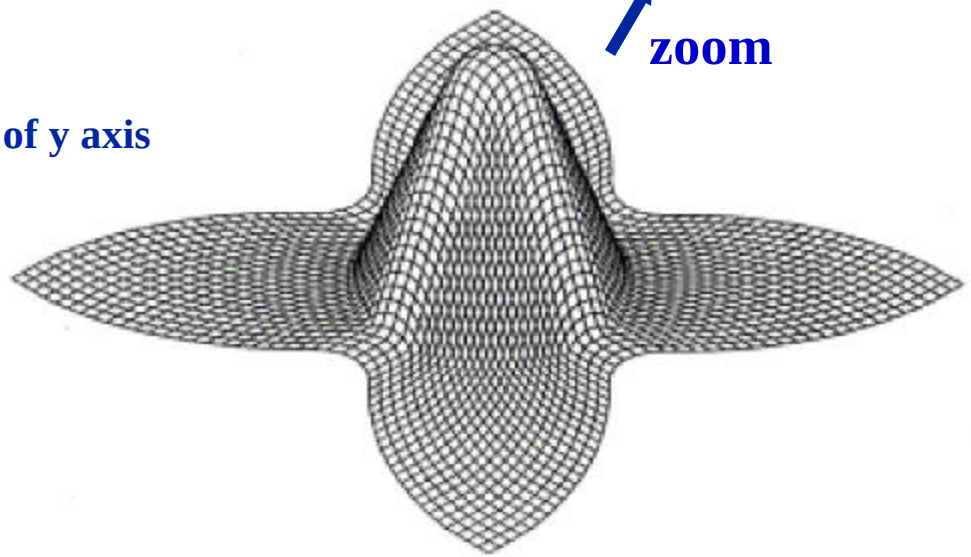


zoom

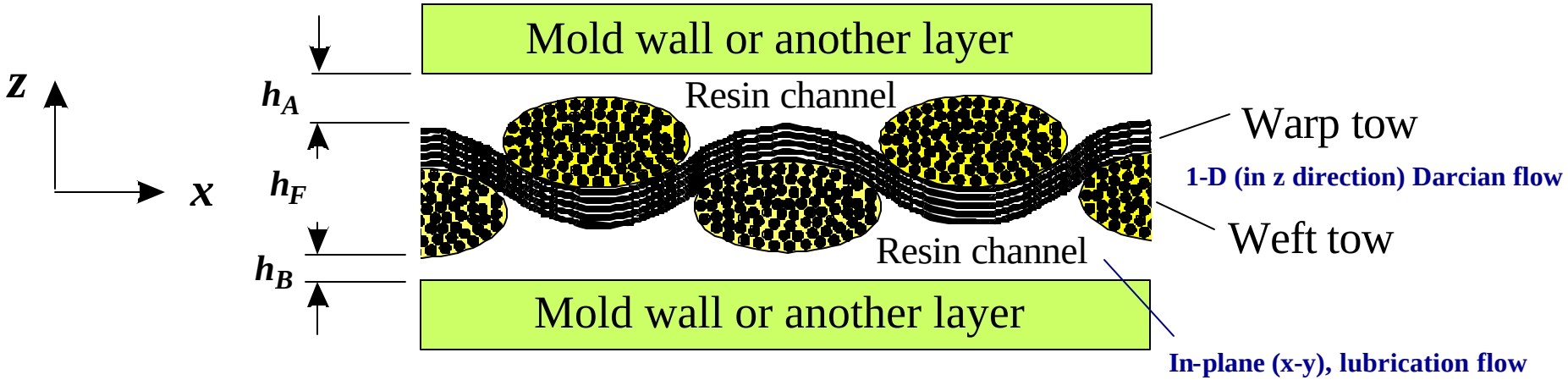
projection of y axis

projection of y axis





Permeability Model for Woven Fabrics



$$-\frac{K_{zz}(p^B - p^A)}{h h^F} - \frac{1}{6h}\left(\frac{\partial\left((h^A)^3 \partial p^A/\partial x\right)}{\partial x} + \frac{\partial\left((h^A)^3 \partial p^A/\partial y\right)}{\partial y}\right) = 0$$

$$\frac{K_{zz}(p^B - p^A)}{h h^F} - \frac{1}{6h}\left(\frac{\partial\left((h^B)^3 \partial p^B/\partial x\right)}{\partial x} + \frac{\partial\left((h^B)^3 \partial p^B/\partial y\right)}{\partial y}\right) = 0$$

Input to model: **geometry:** $h_A(x,y), h_F(x,y), h_B(x,y)$ **Output:** K_{xx}, K_{yy}, K_{xy}

transverse permeability: K_{zz}

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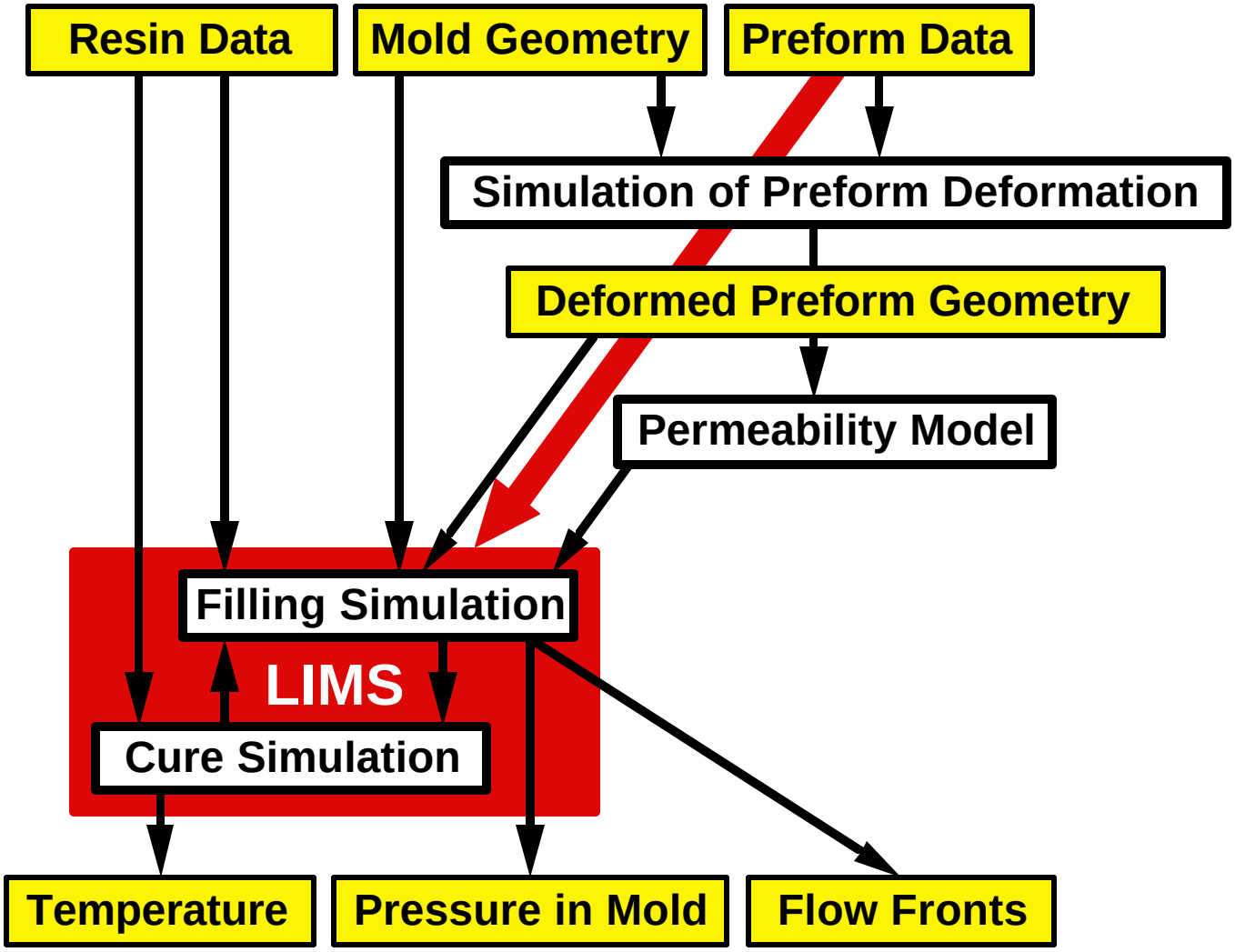
Modeling Flowchart



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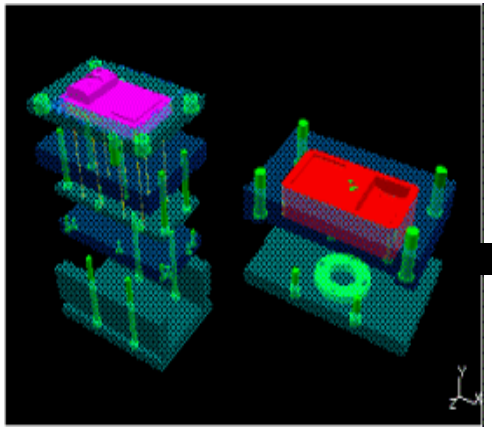
Liquid Injection Molding Simulation

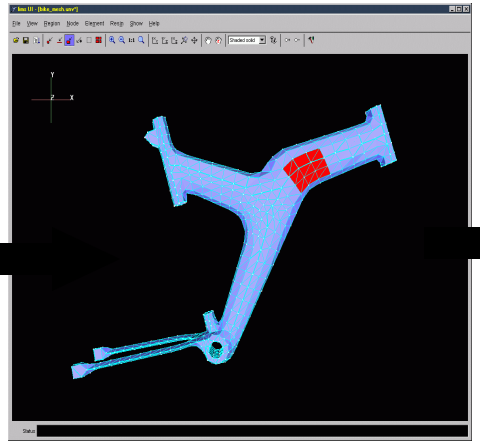
- Finite Element / Control Volume solver
- Optimized algorithms result in very fast computational time
- Use of 1-D, 2-D and 3-D elements

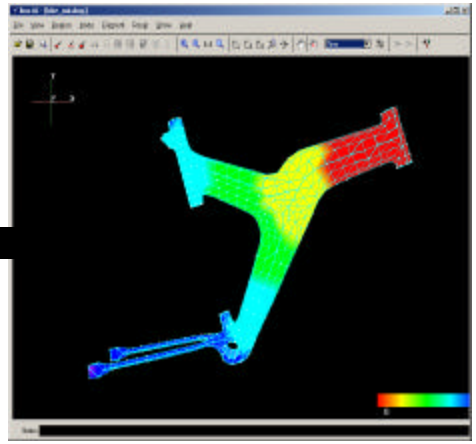
1- Mesh Generation in IDEAS, etc.

2- Material Properties, simulation interface

3- Results







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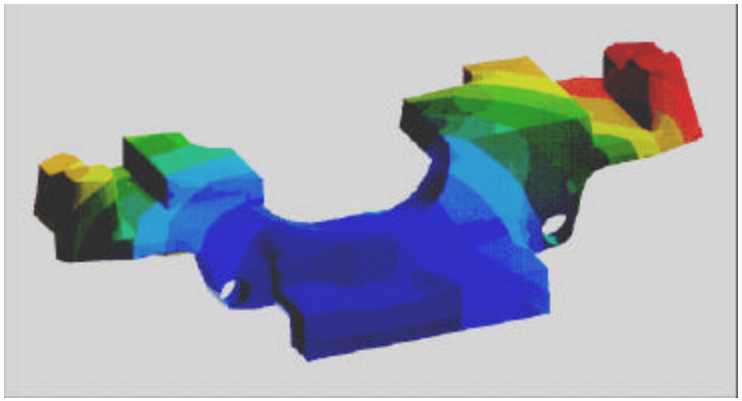
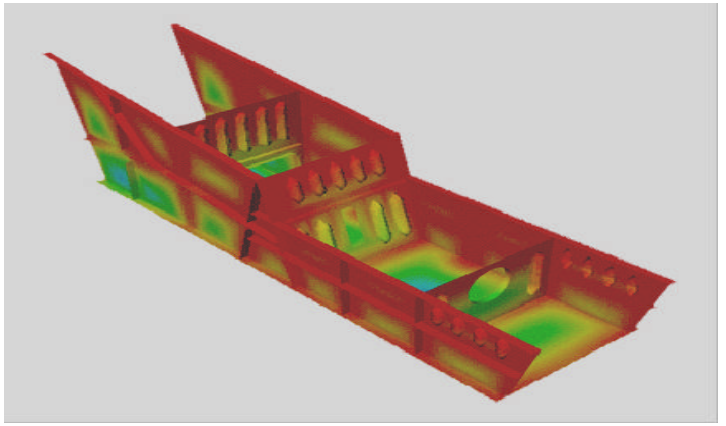
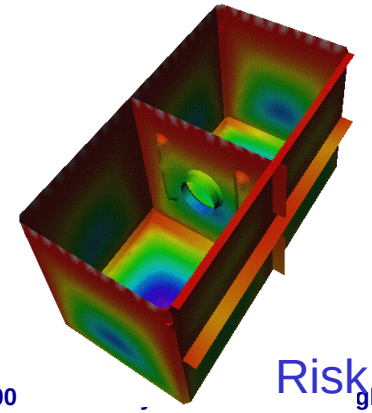
Mold Filling Simulations for 2-D/3-D "Shell" Geometries



Cross-member of a passenger van



Comanche Helicopter : Keel Beam



Risk Reduction Box

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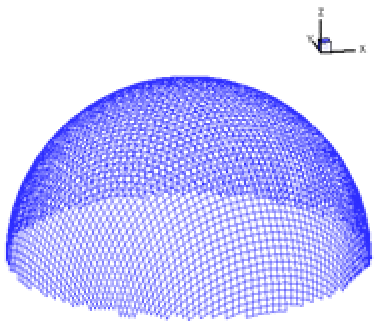
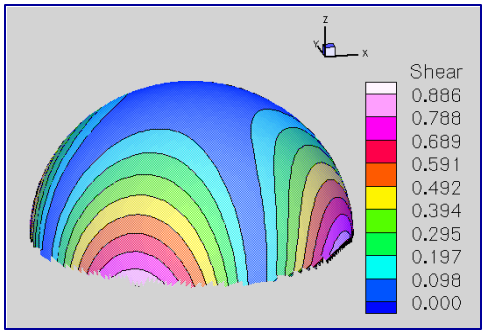
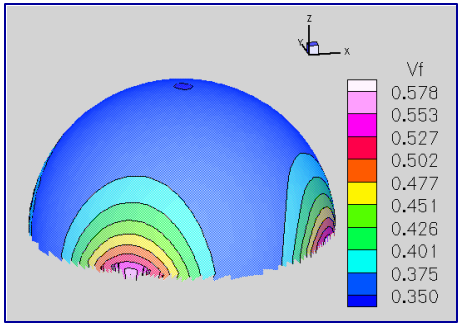
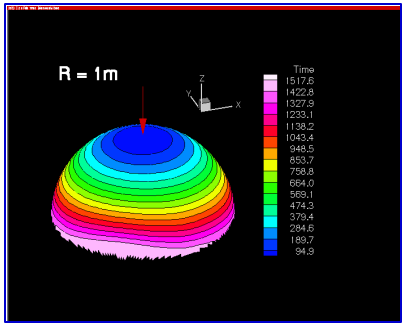
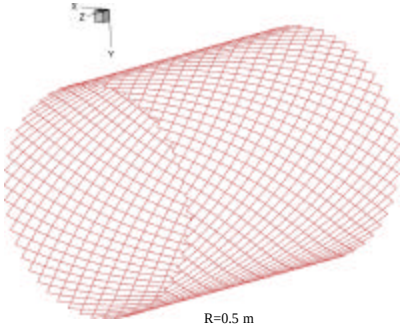
Influence of Draping

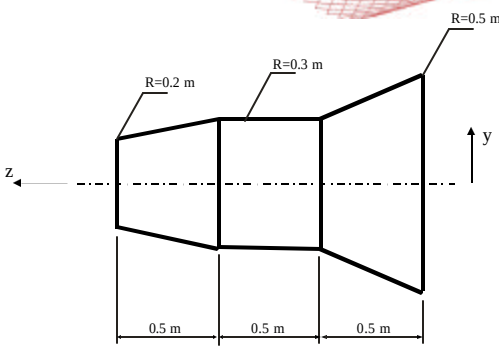


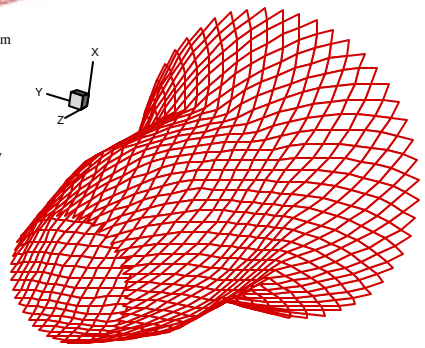




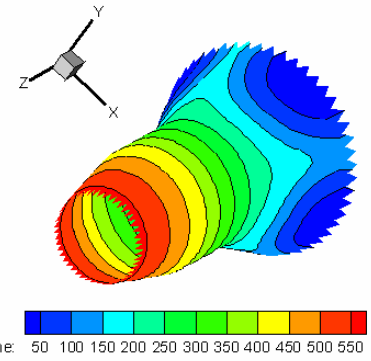






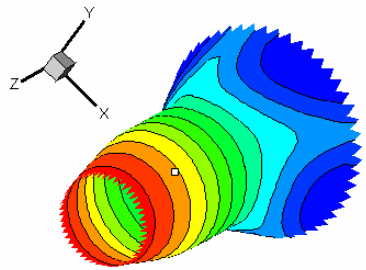


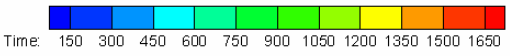
NO DRAPING EFFECT ON K



Filling time = 562 s.

DRAPING EFFECT ON K





Filling time = 1717 s.

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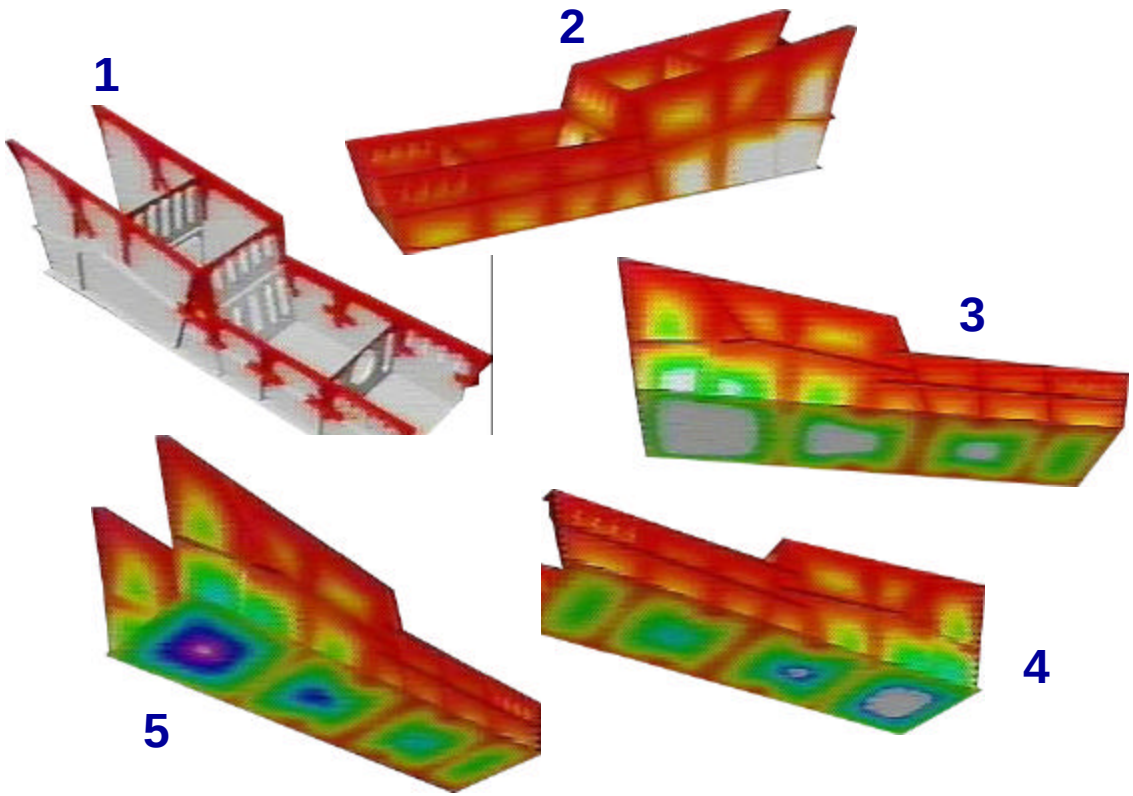
Mold Filling Simulation of Keel Beam Showing Time History of Resin Flow



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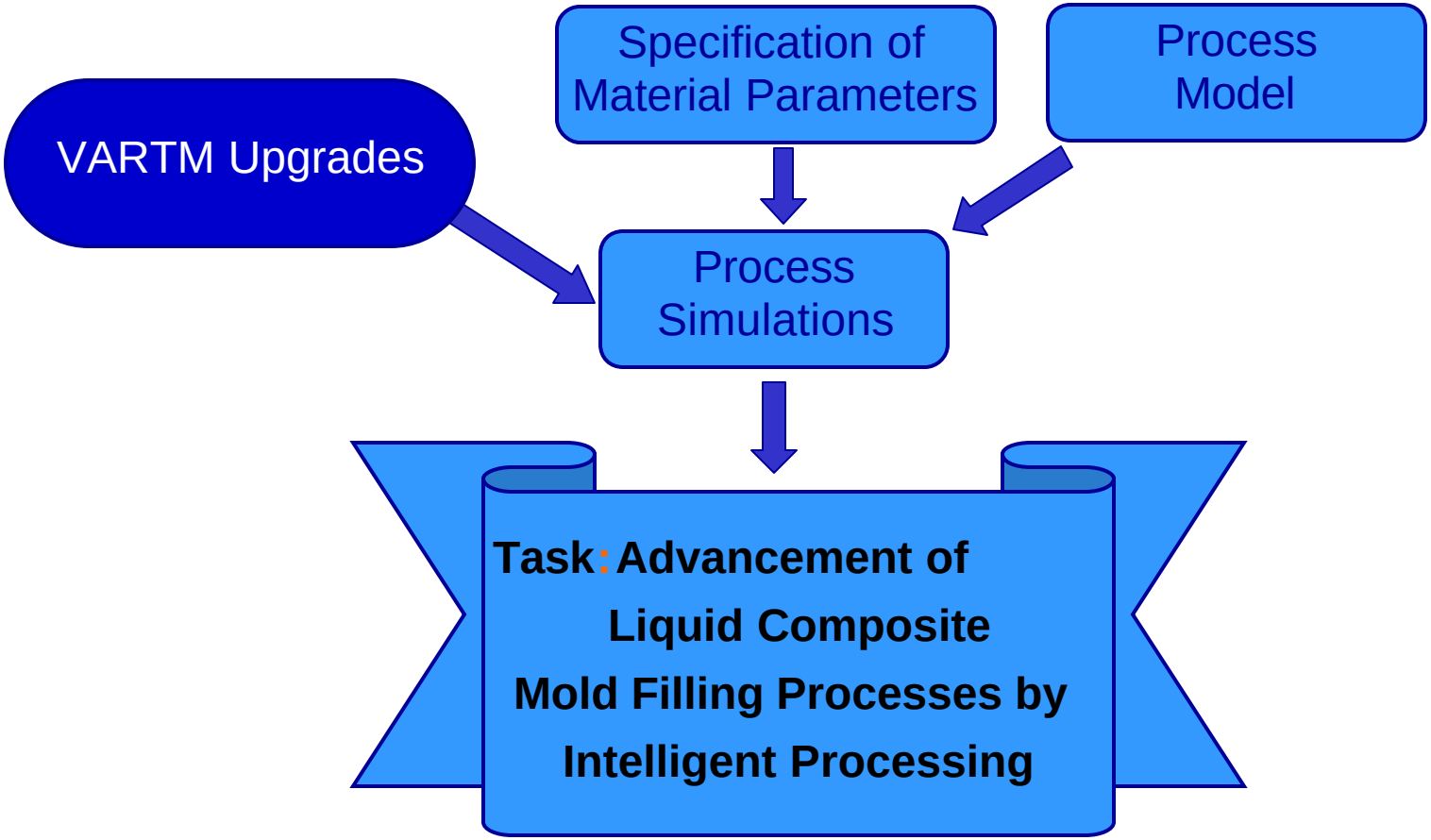
Modeling issues specific to VARTM process



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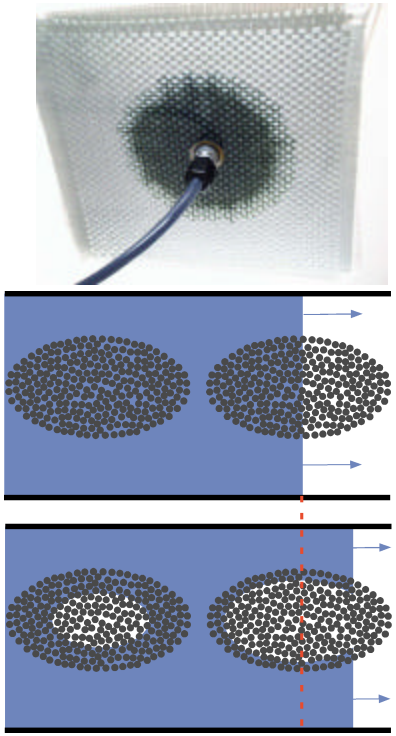
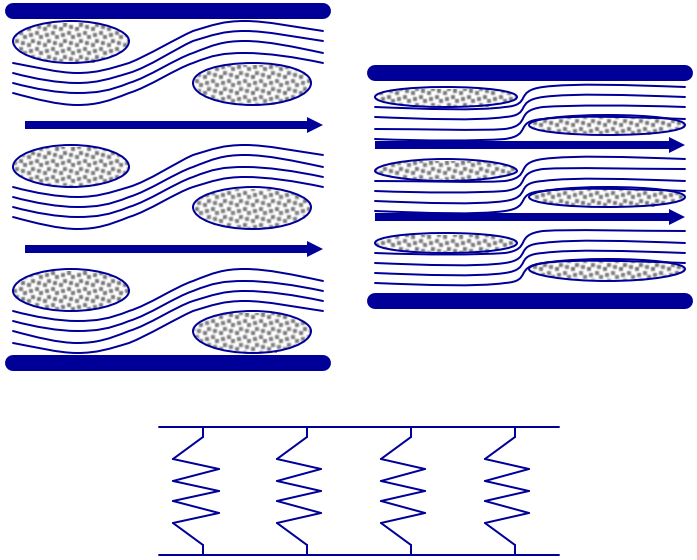
Modeling VARTM in Simulations

Tow Saturation



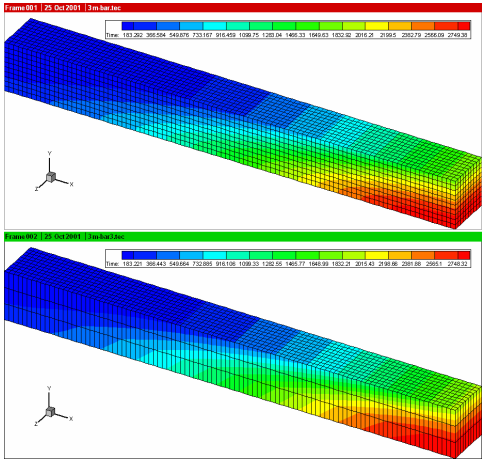
$$\nabla\left(\frac{\mathbf{K}}{h}\nabla p\right) = q(p,s)$$

Compaction

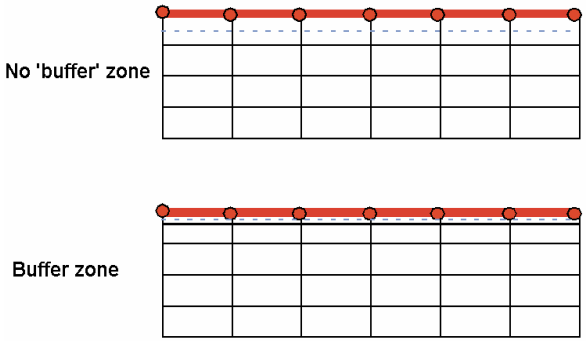


$$Patm - P = As\frac{\left(\sqrt{\frac{v_f}{v_o}} - 1\right)}{\left(\sqrt{\frac{v_a}{v_f}} - 1\right)^4}$$

Distribution Media



1D distribution media model



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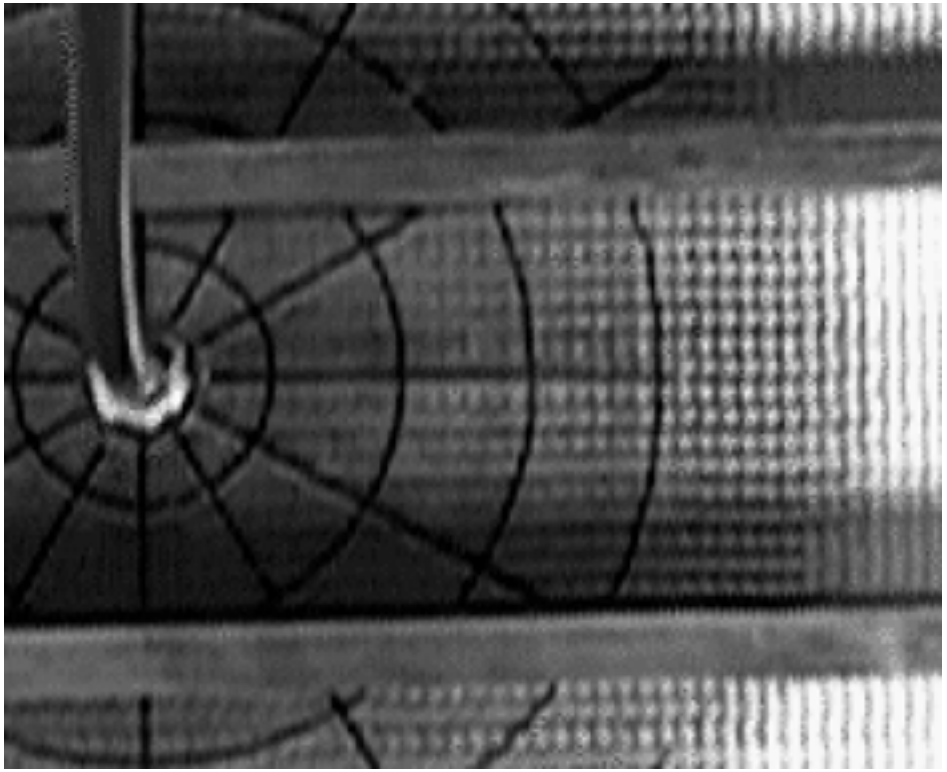
Fluid Impregnation in Fiber Tows



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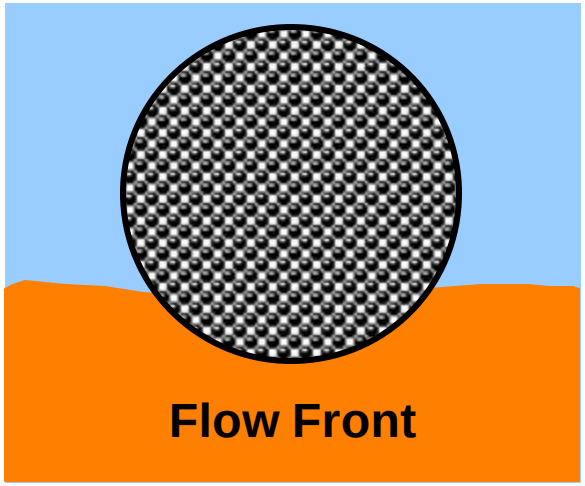
Dual Scale Porous Media

1.



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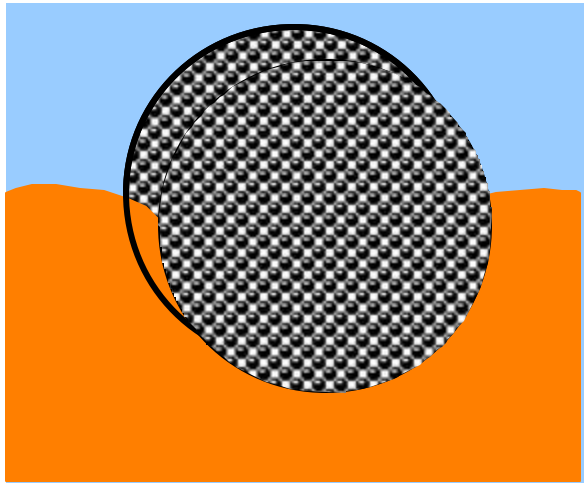

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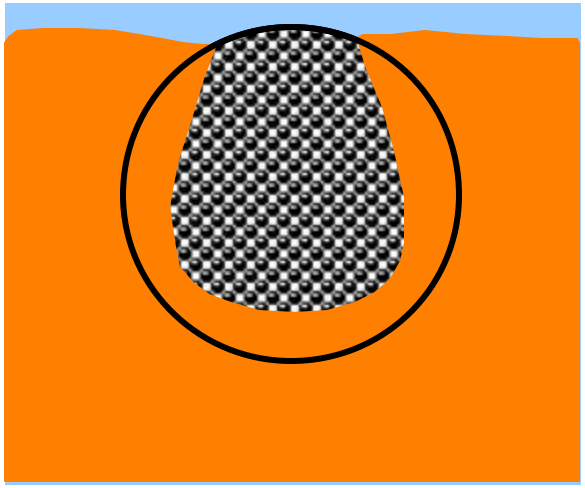

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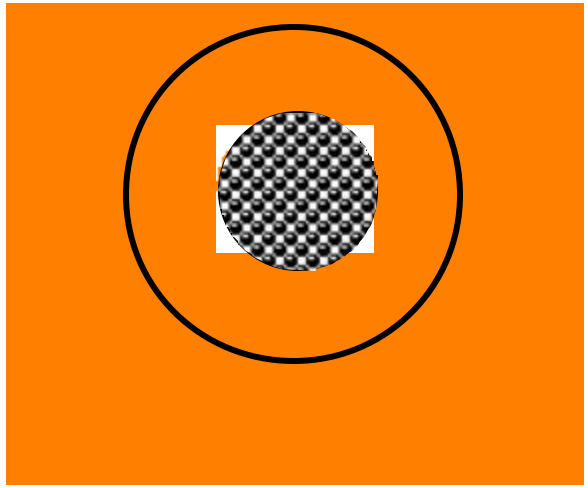

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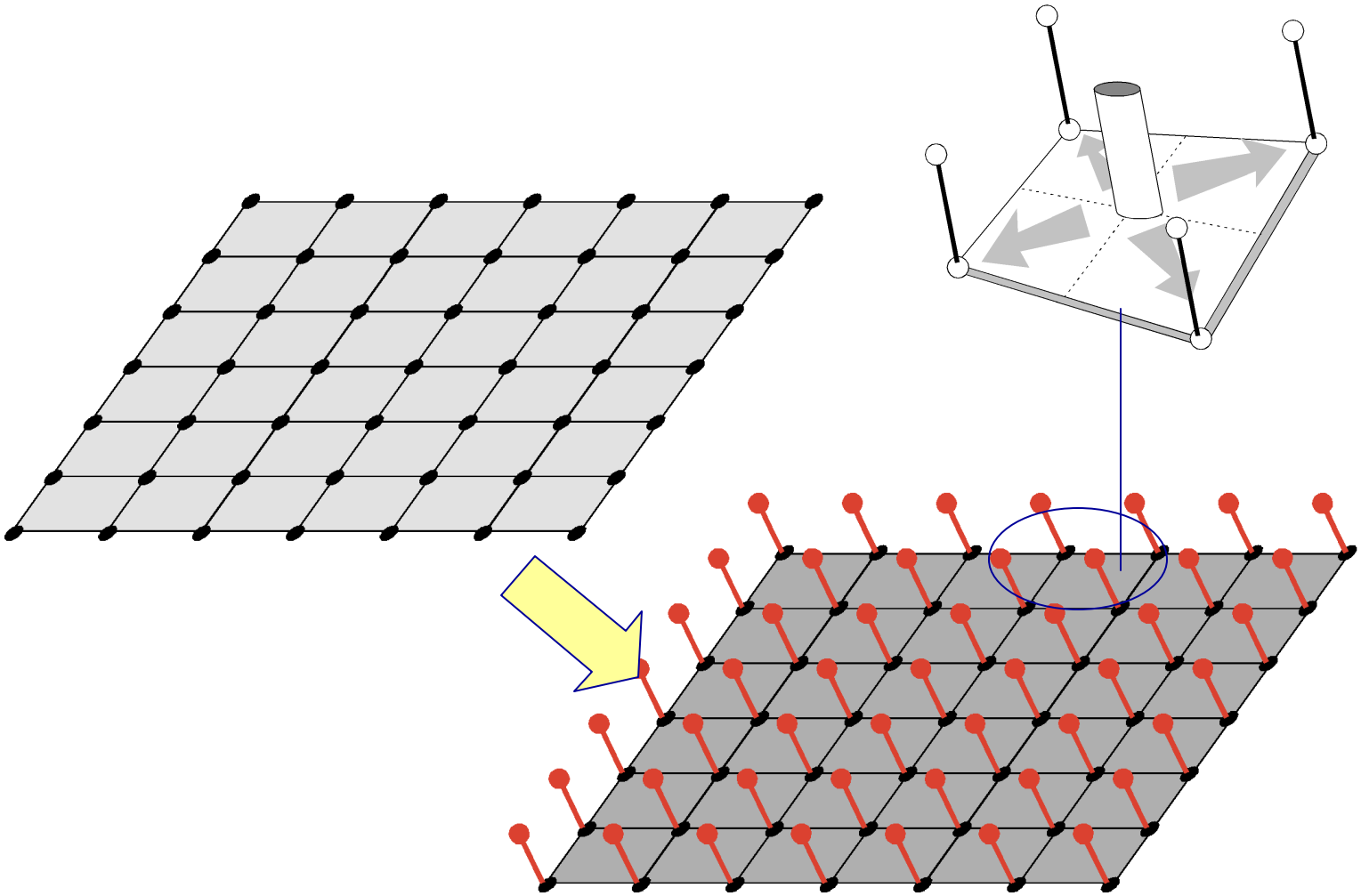
Saturation Modeling In LIMS : Mesh Modification



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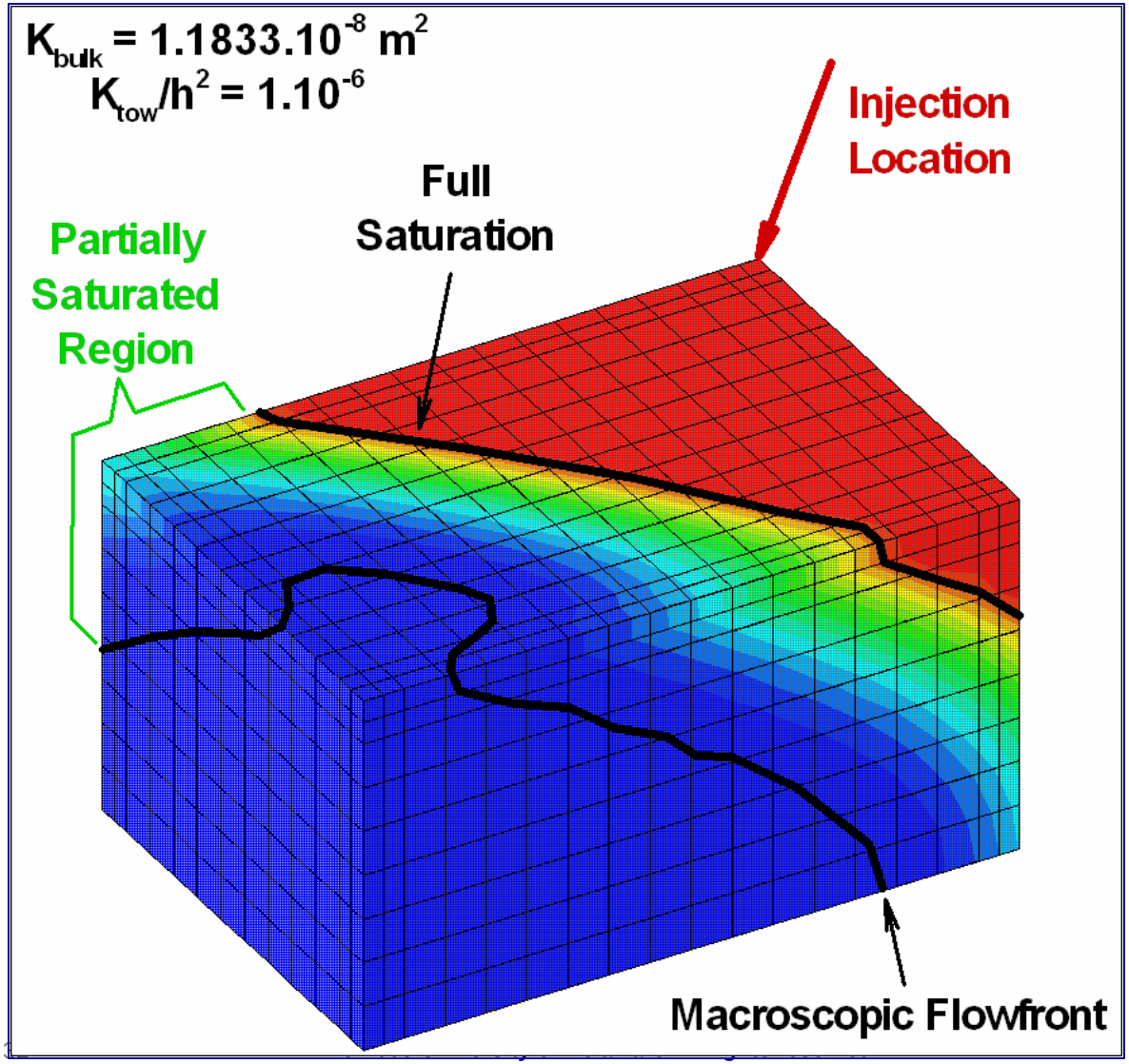
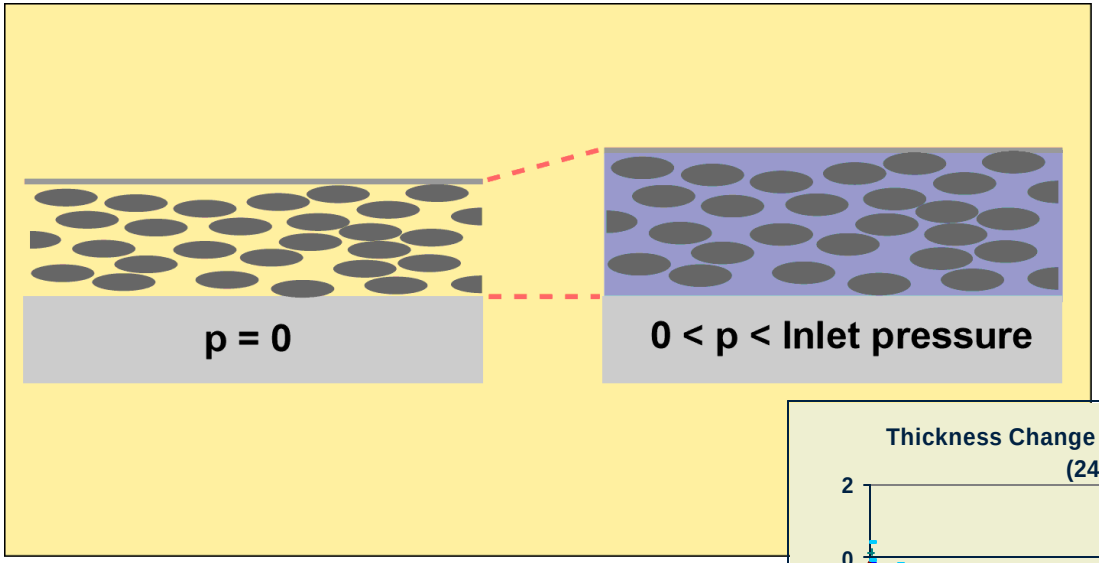
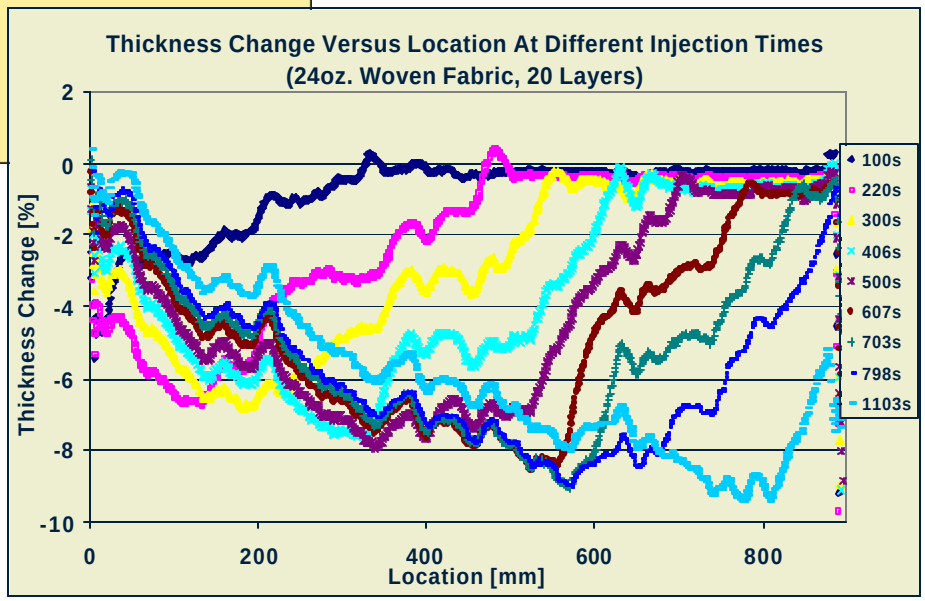
Simulation of Saturation Effect



Preform Compaction





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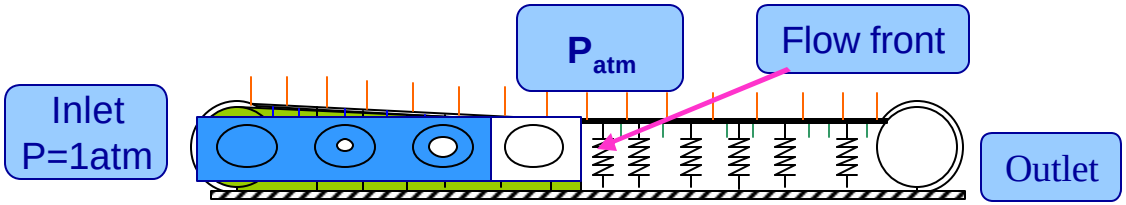
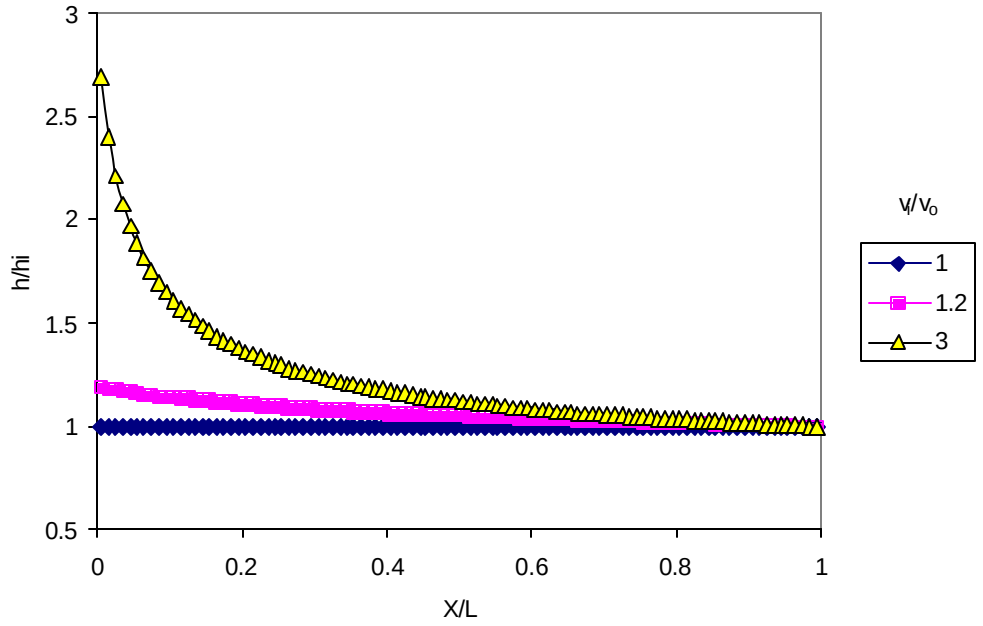
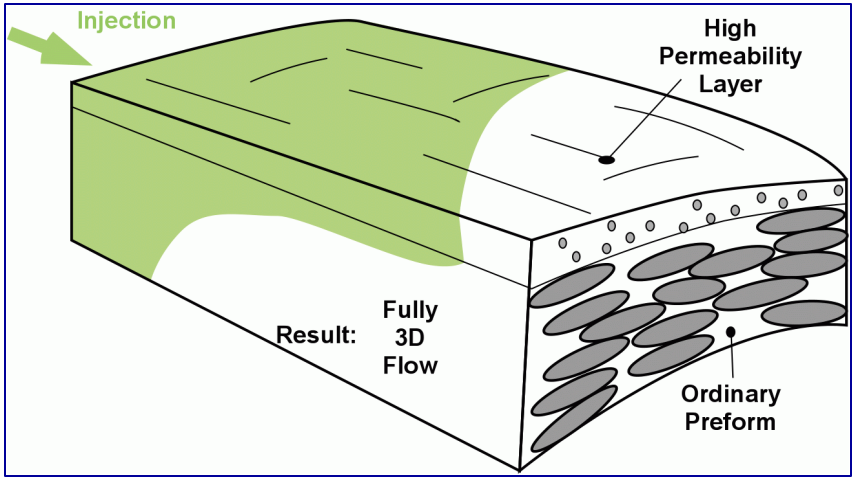
1-D Coupled Flow and Compaction Model



$$\frac{\partial}{\partial x}\left(K_{xx}\frac{v_i}{v_f}\frac{\partial P}{\partial x}\right)=m\frac{\partial}{\partial t}\left(\frac{v_i}{v_f}\right)+\frac{2K_{TOW}P}{R^2}\frac{v_f}{v_{f\,TOW}}\frac{\sqrt{1-S}}{1-\sqrt{1-S}}$$



Distribution Media Modeling



- 3-D flow effects
- Distribution media layer is thin
- Numerical difficulties in 3-D modeling
  - Element aspect ratio is high

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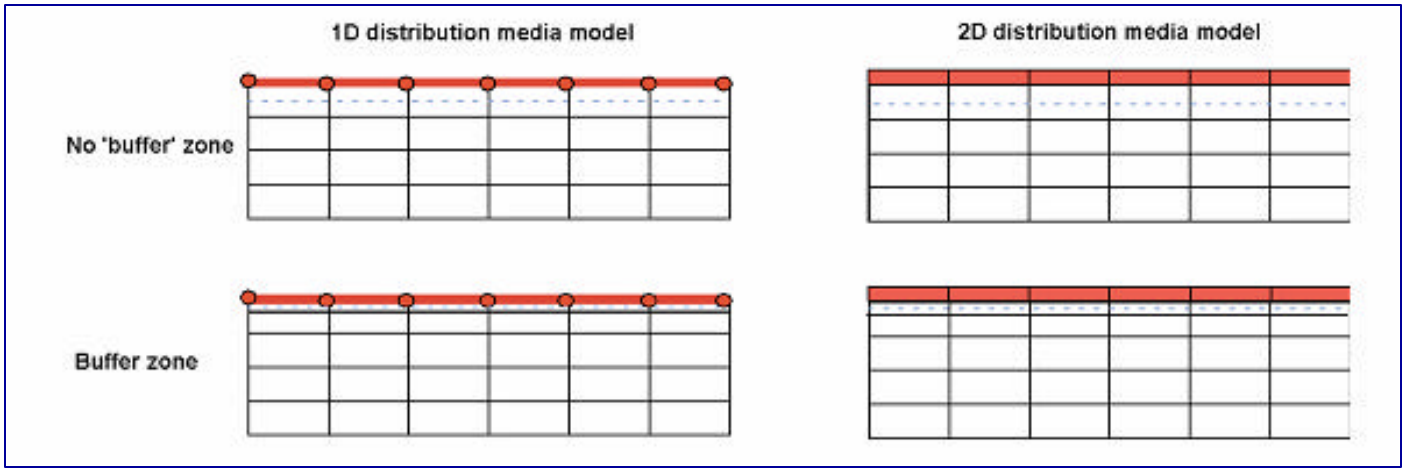
How To Model Distribution Media?

- How to Defeat Numerical Problems with High Aspect Ratio Elements?



- How Coarse Can the Mesh Be?
- How to Address the Unknown DM Transverse Permeability?

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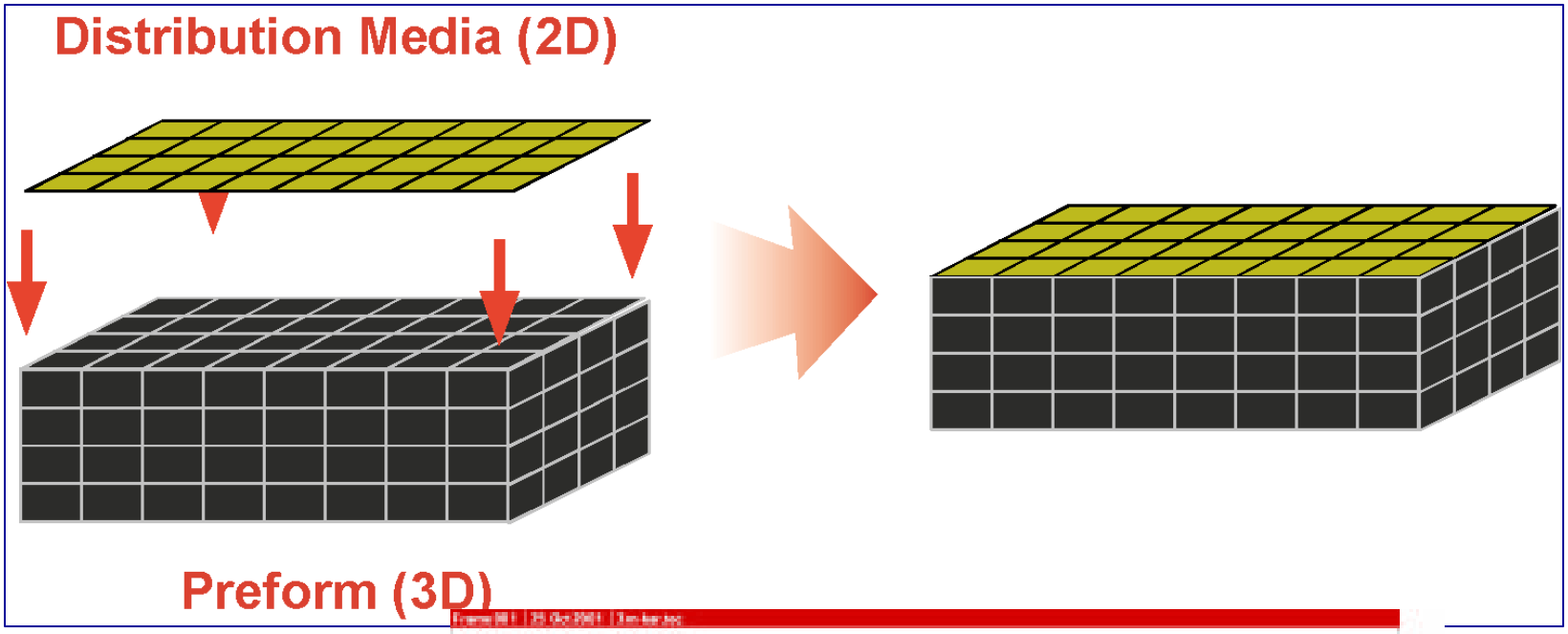
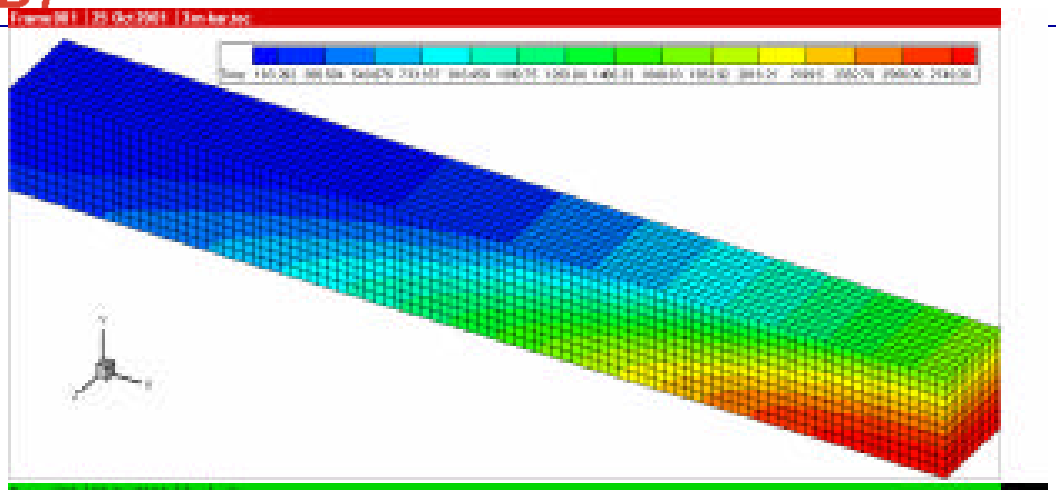
2D Distribution Media Model





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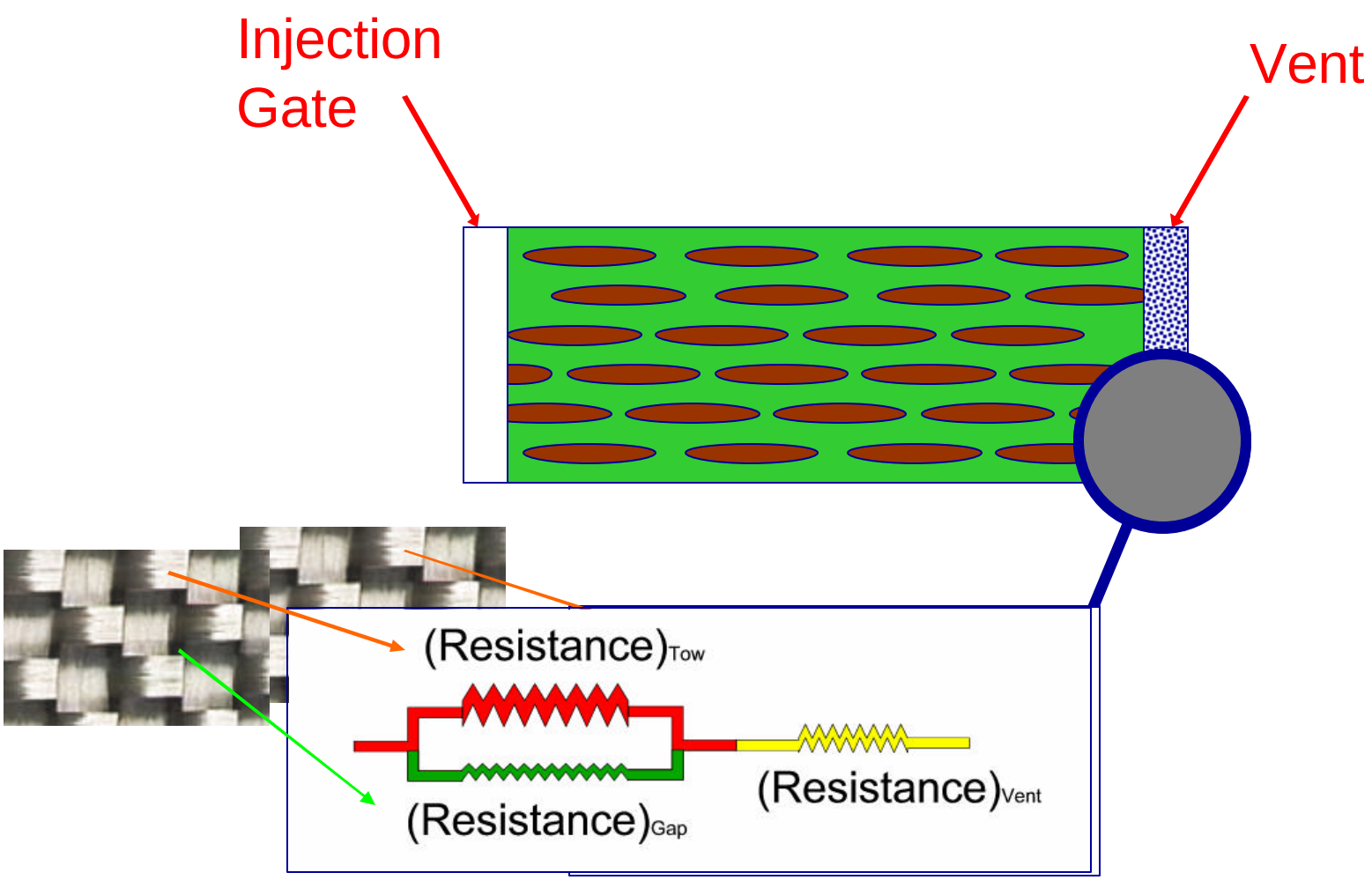
Problem- Resin Wastage



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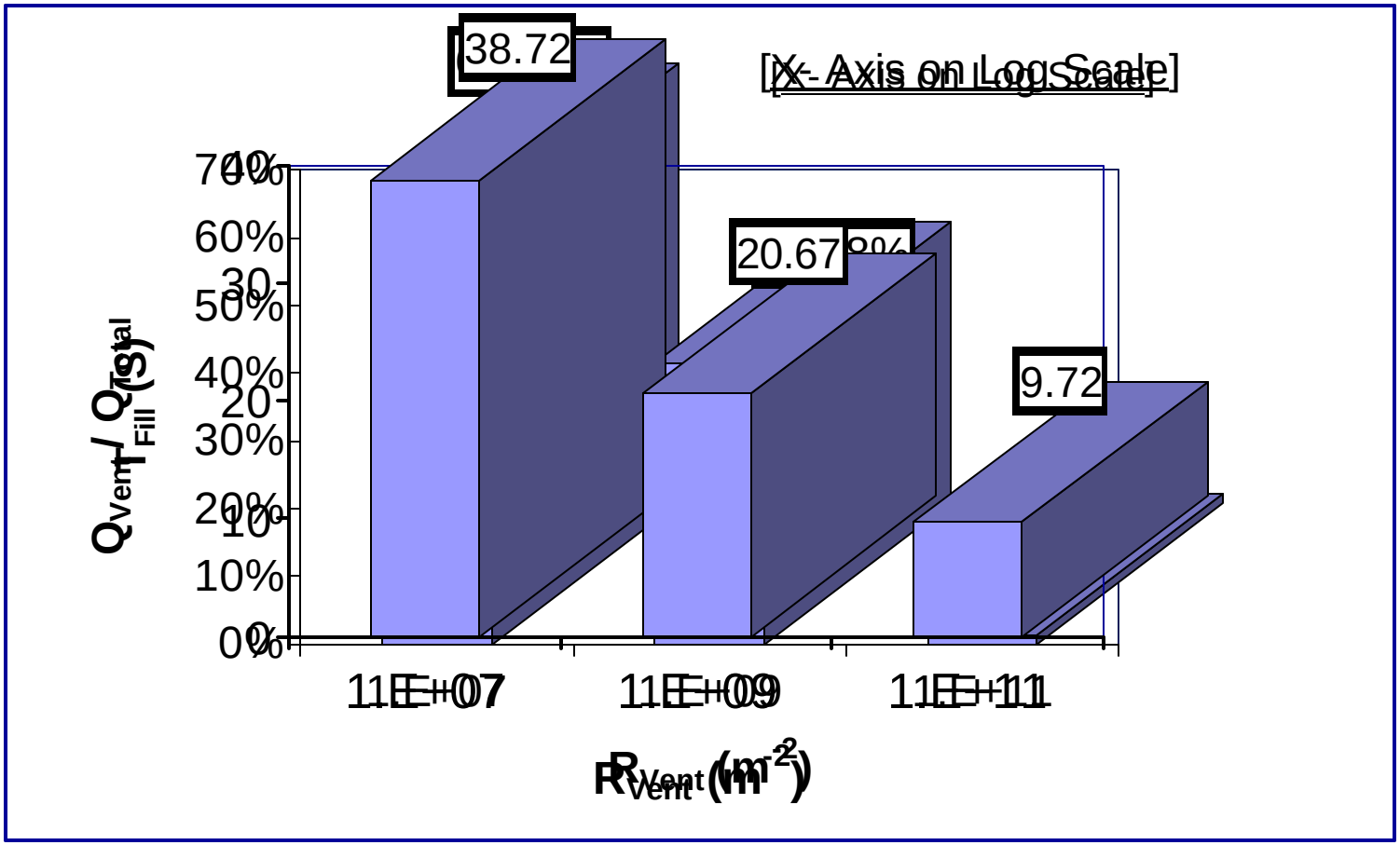
Influence of Vent Resistance



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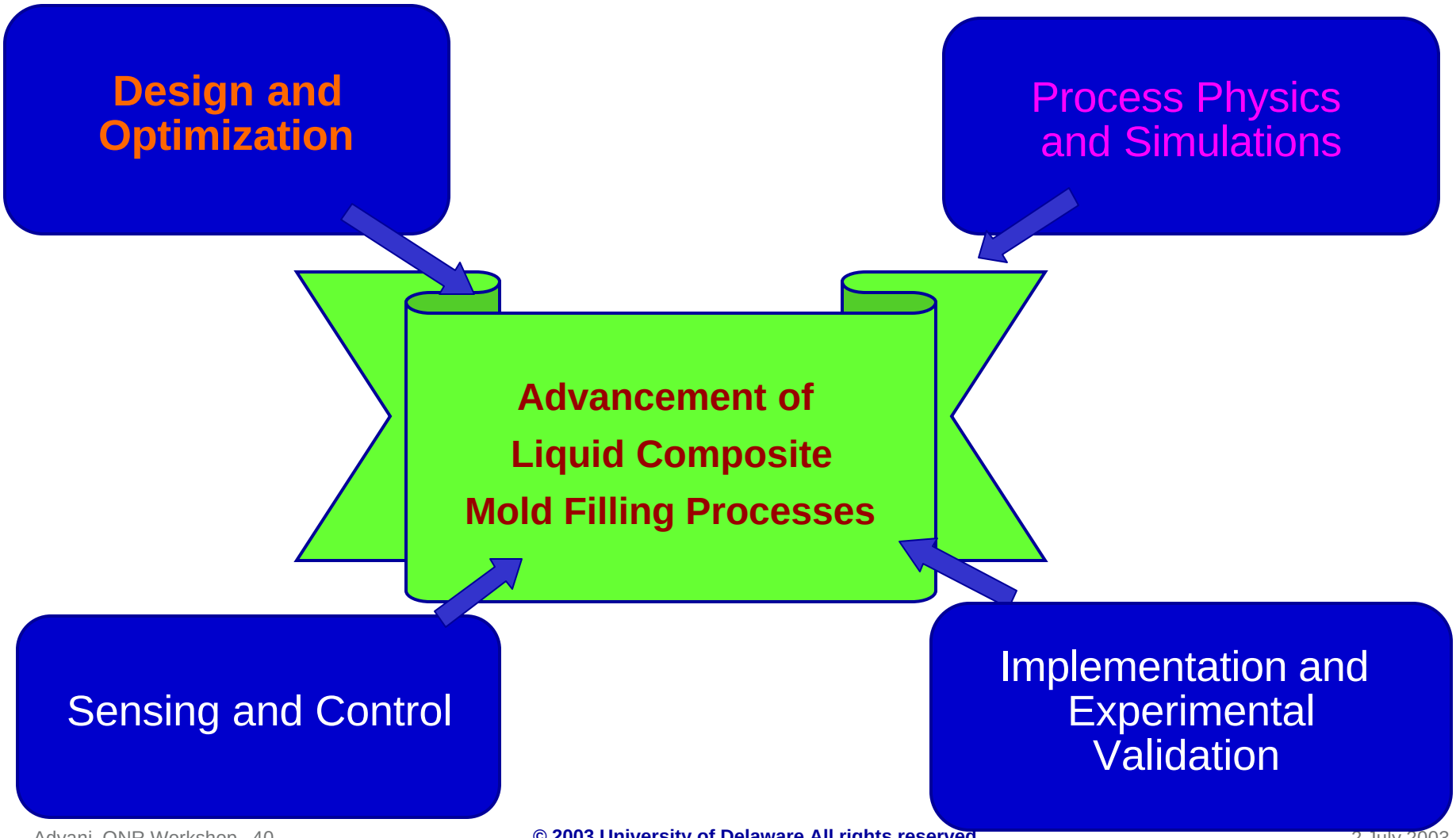
Design and Optimization



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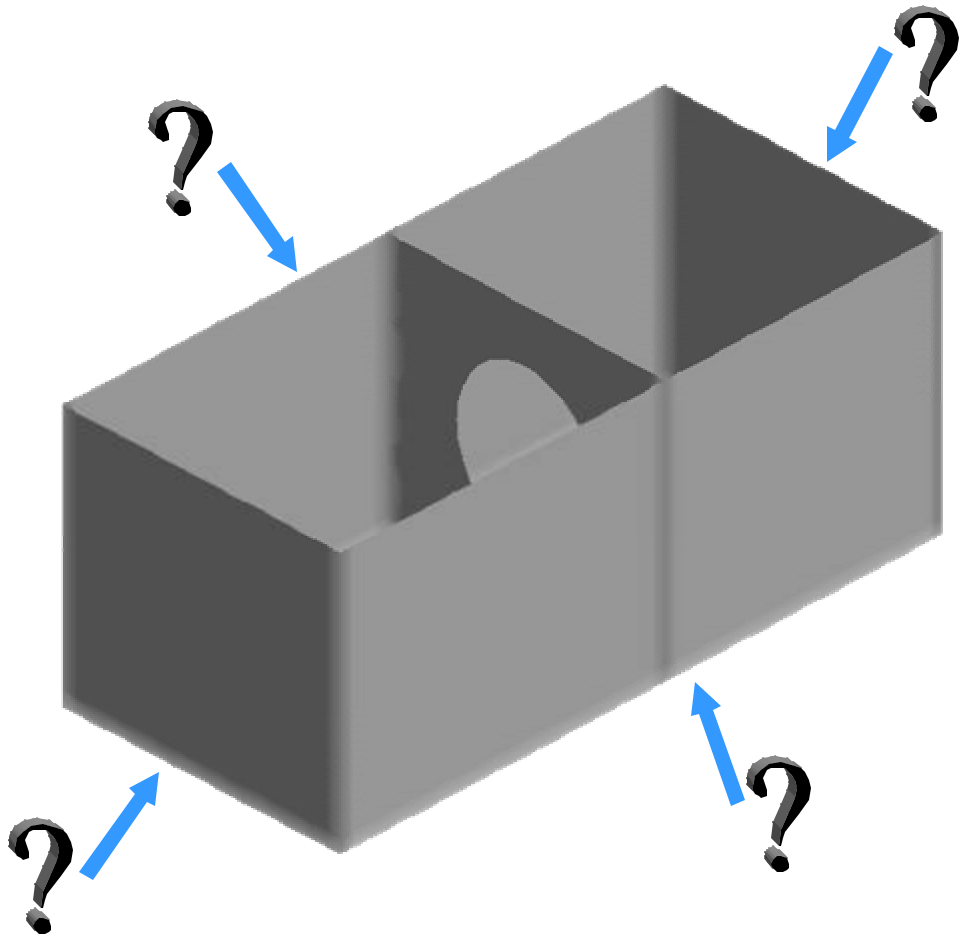
Design for Best Gate Location

Criteria:

- **Minimum no of Gates**
- **Minimum Fill Time**
- **No Voids**
- **Low Pressures**



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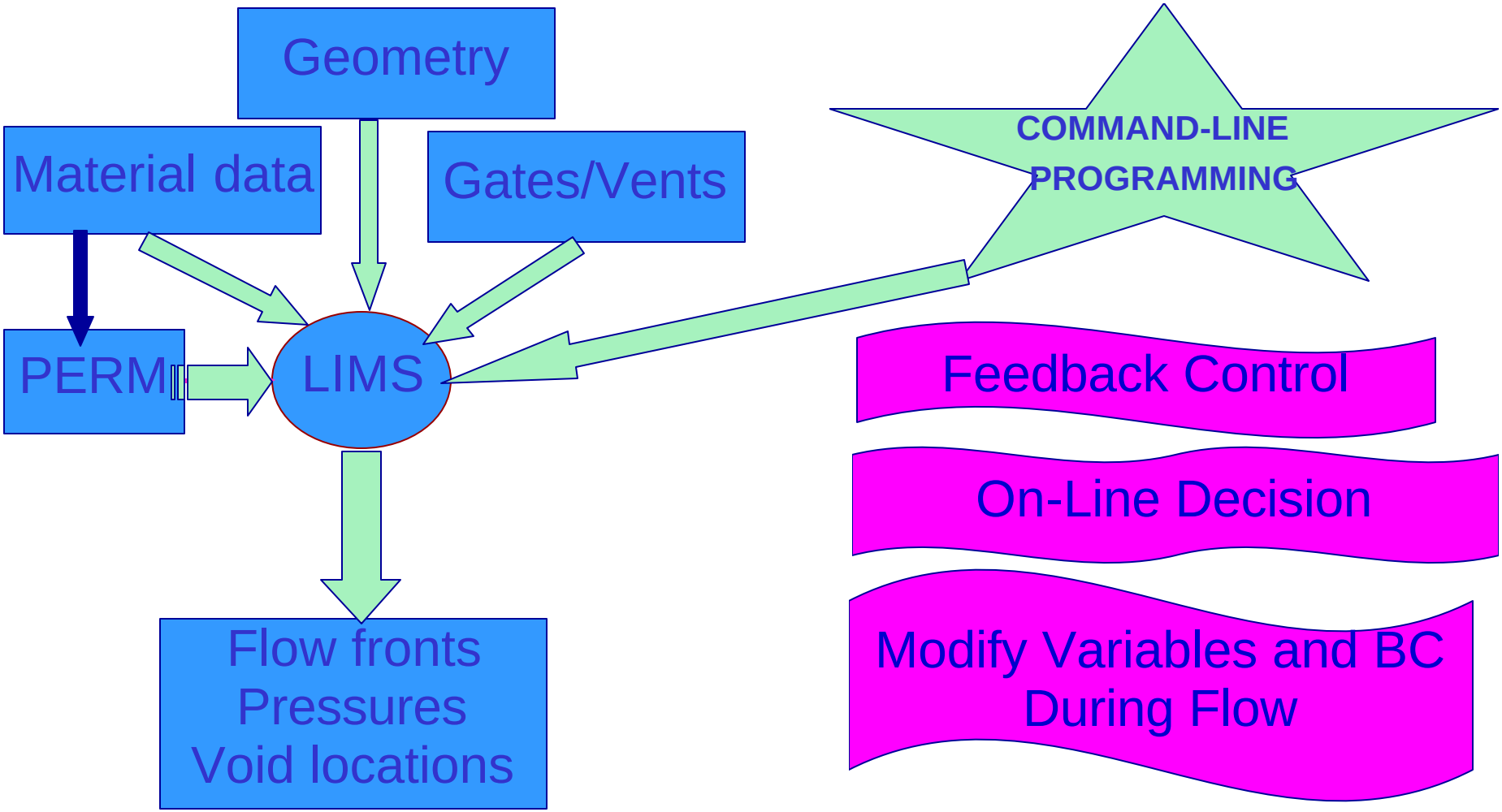
Approach to Use of Simulations for Design, Optimization and Control



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Command Line Control

Script file:

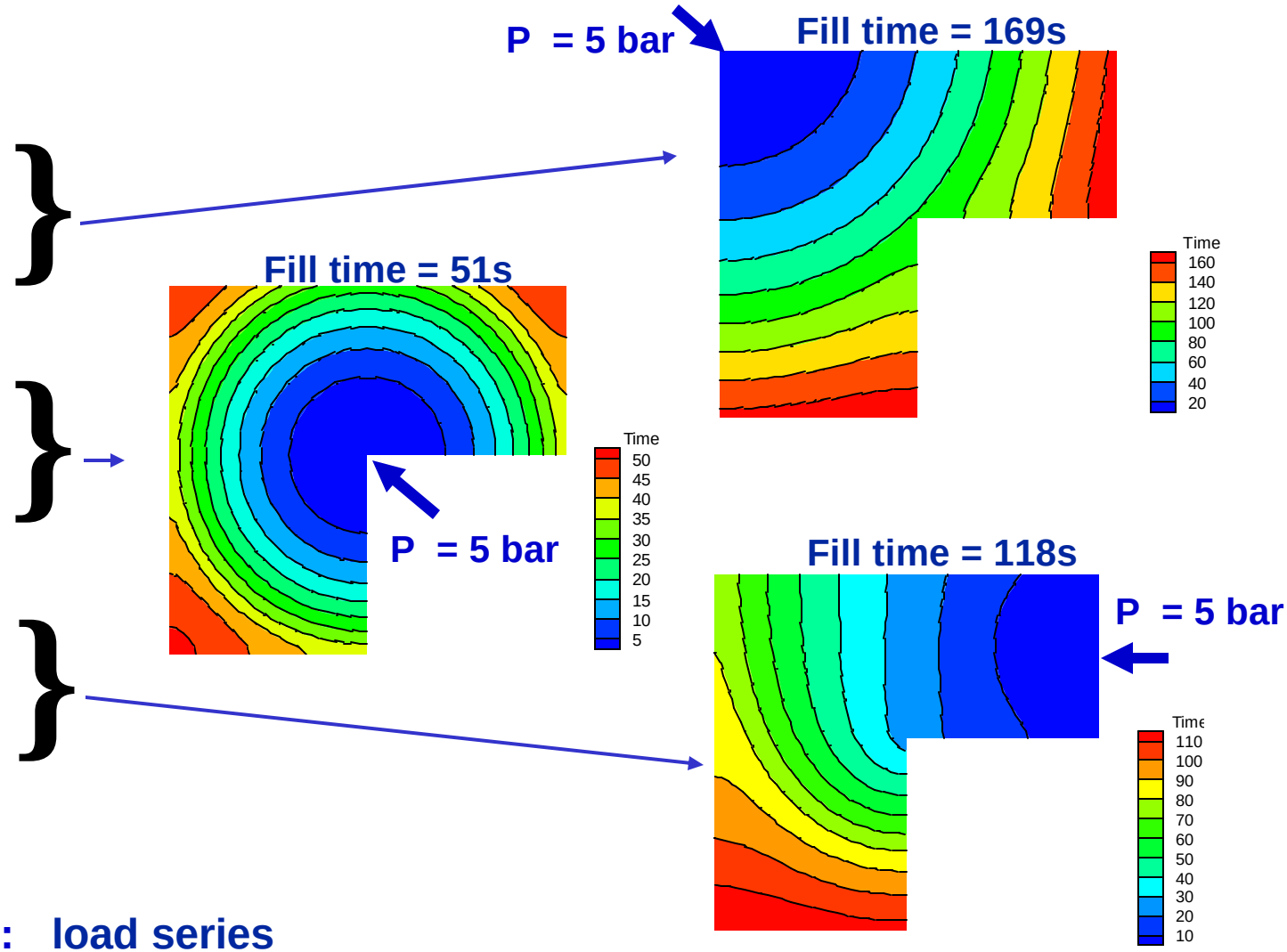
```
proc series

settime 0.0
read "ellshape.in"
setgate 51,1,500000
auto
setouttype "tplt"
write "ell_1"

settime 0.0
read "ellshape.in"
setgate 51,0,0
setgate 1301,1,500000
auto
setouttype "tplt"
write "ell_2"

settime 0.0
read "ellshape.in"
setgate 51,0,0
setgate 1963,1,500000
auto
setouttype "tplt"
write "ell_3"

endproc series
```



On command-line: load series

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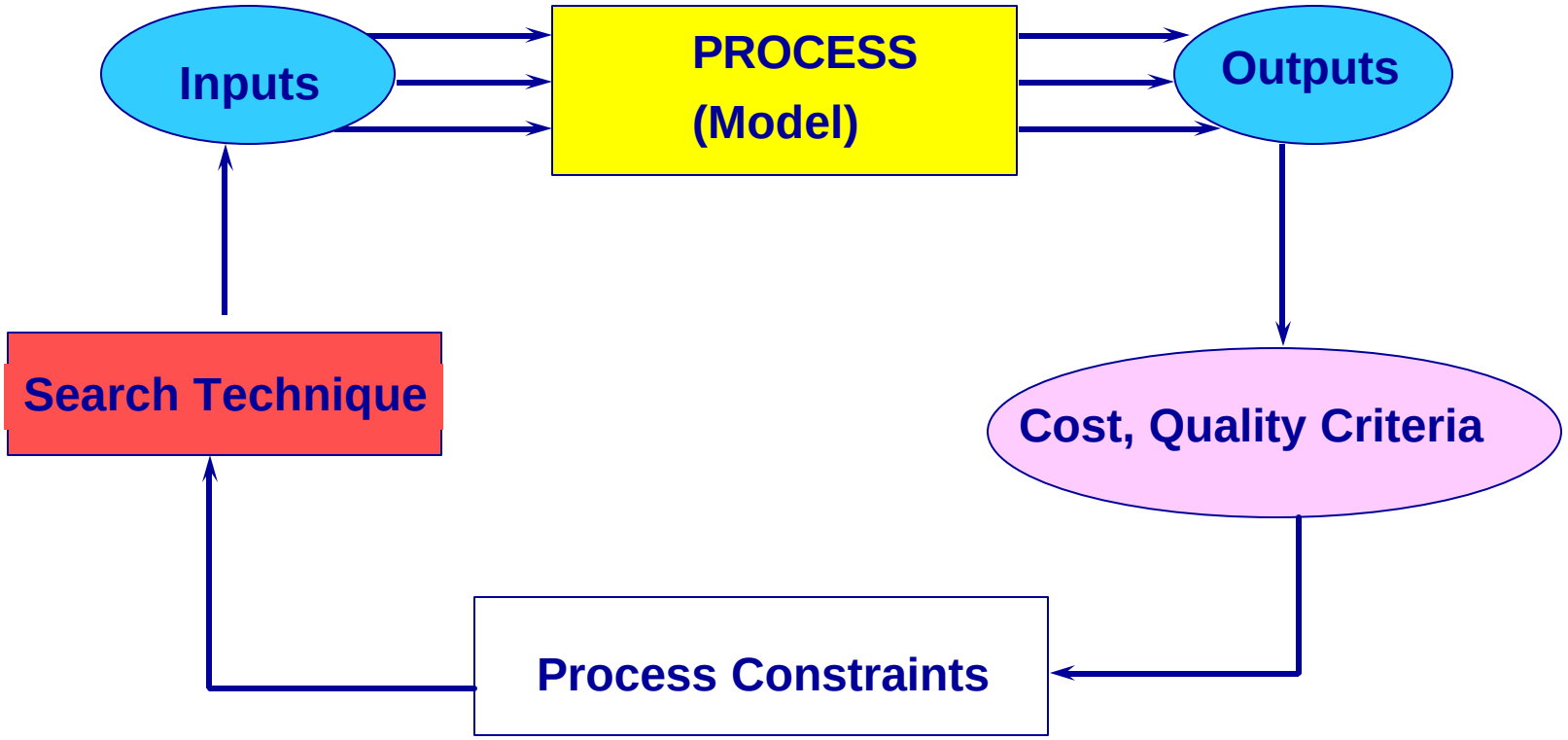
Model-Based Optimization



Search Techniques :

- **Heuristic (Experimental / Experience based)**
- **Analytical (Gradient Based)**
- **Probablistic (genetic algorithms)**

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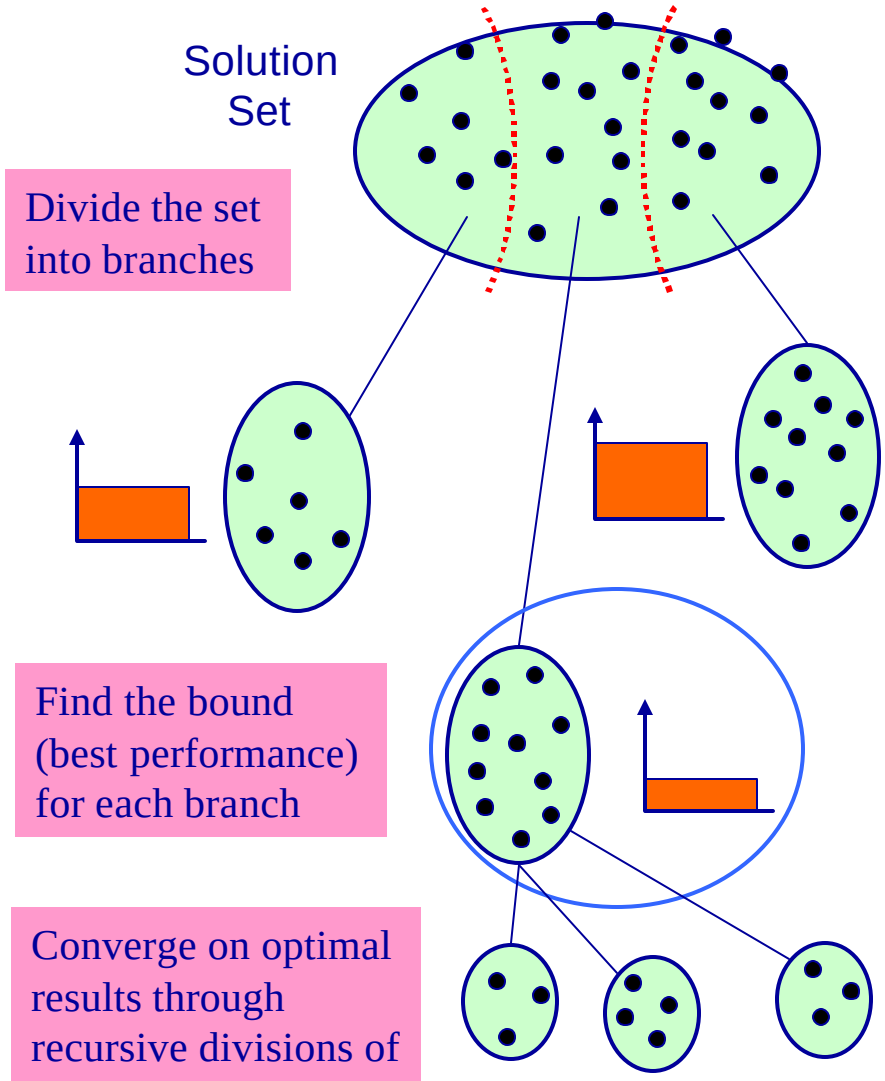
Branch and Bound Search (BBS)



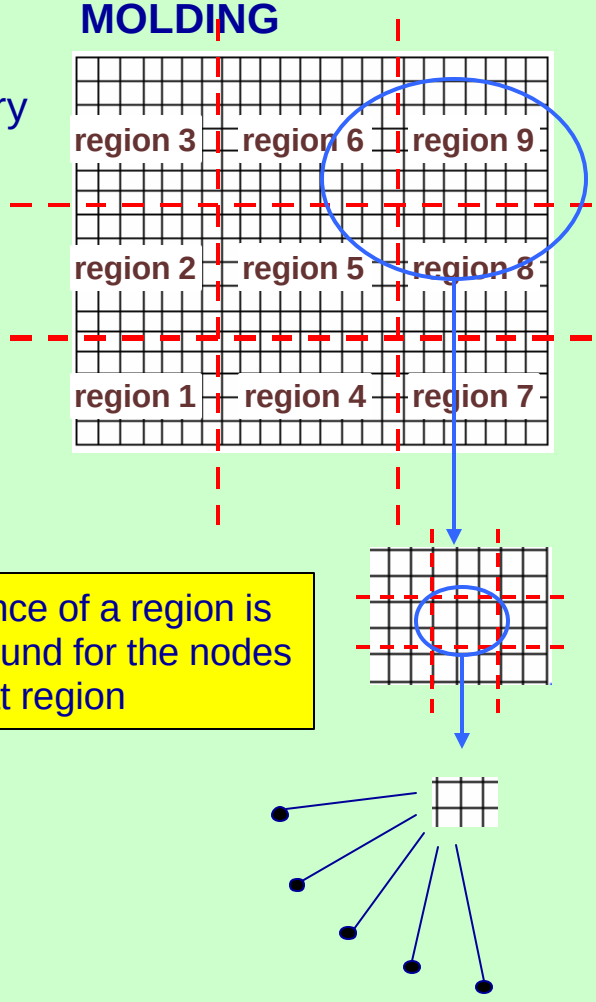
Divide the set into branches

Find the bound (best performance) for each branch

Converge on optimal results through recursive divisions of superior branches

RESIN TRANSFER MOLDING

Mold Geometry



All nodes in a regions act as identical gates

The performance of a region is taken as the bound for the nodes in that region

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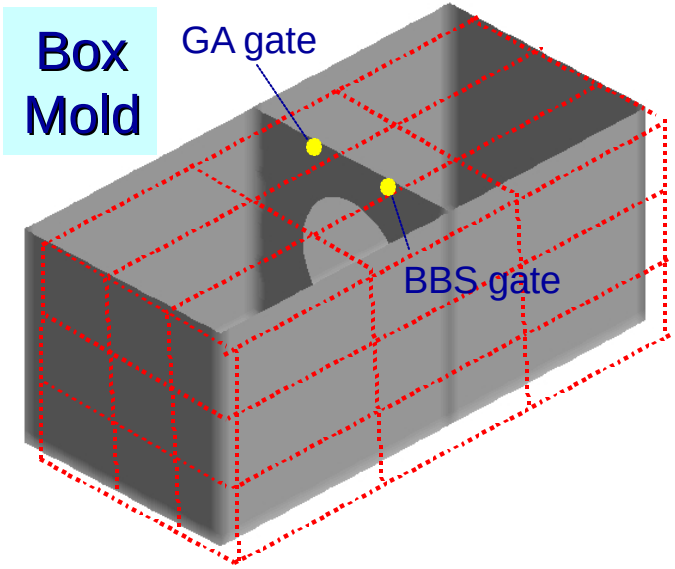
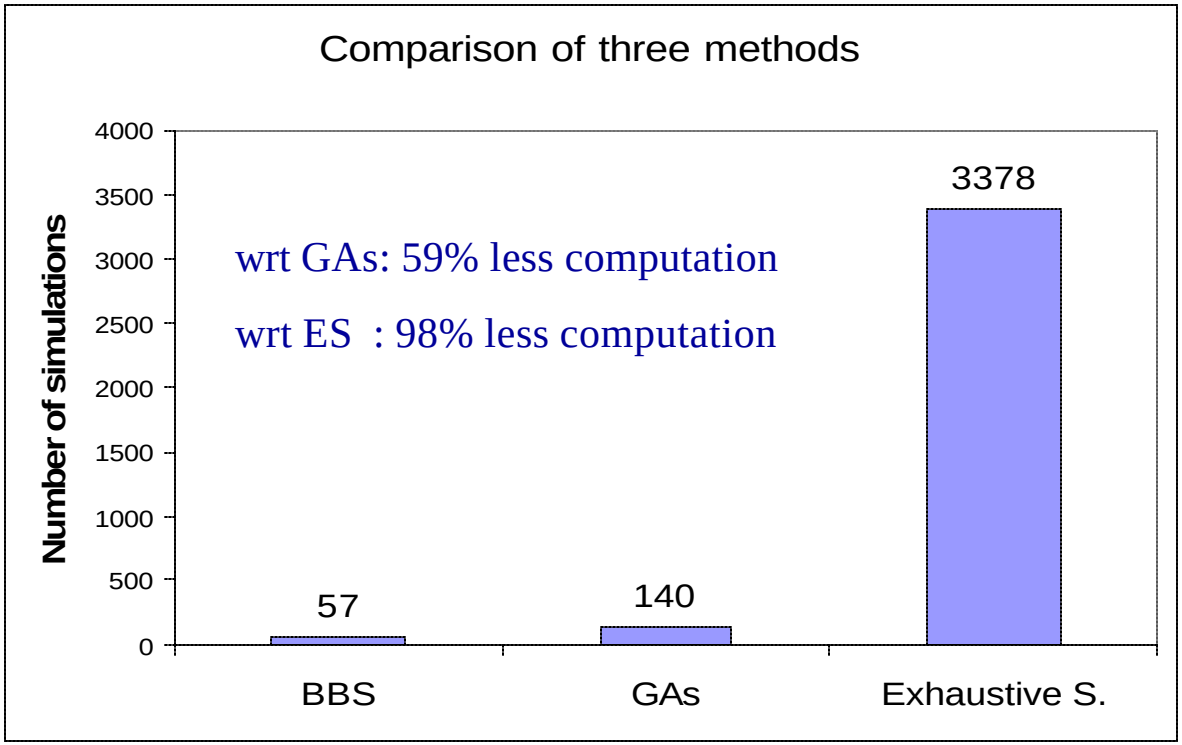
Results & Comparison - Box Mold





Best Fill Times

BBS: 9995 sec

Genetic Algorithms 10,862 sec

Exhaustive Search 9,995 sec

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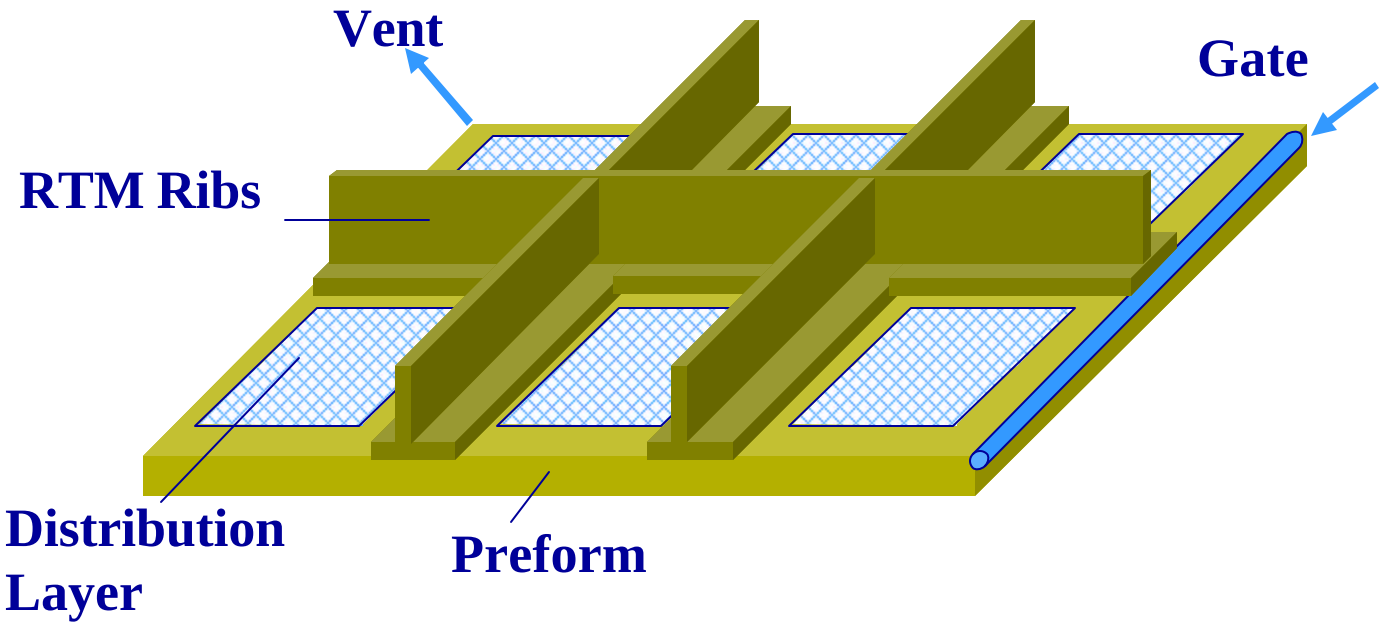
Use of SLIC to Optimize Distribution Media



What is the optimized flow distribution network design?

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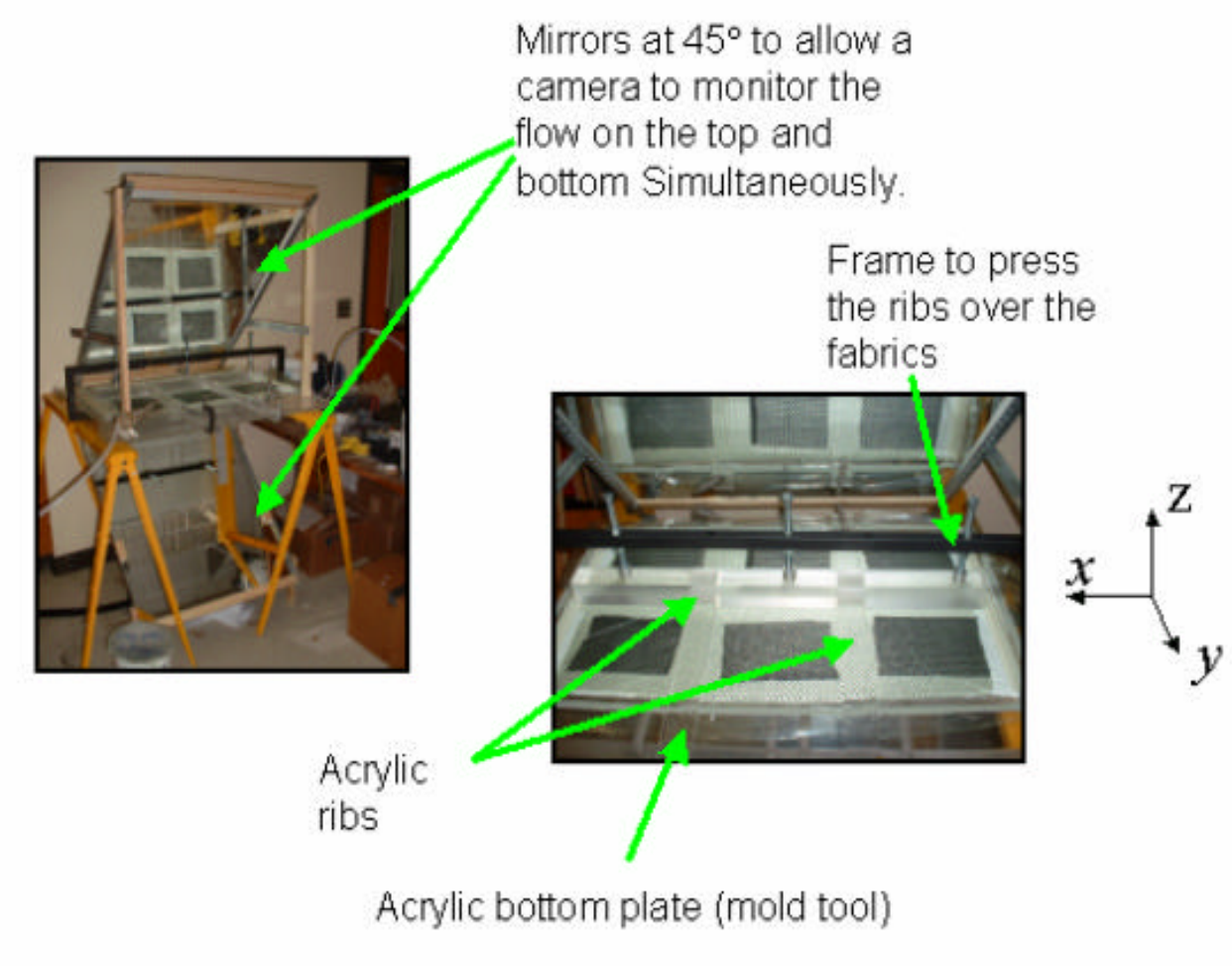
Experimental Set-Up



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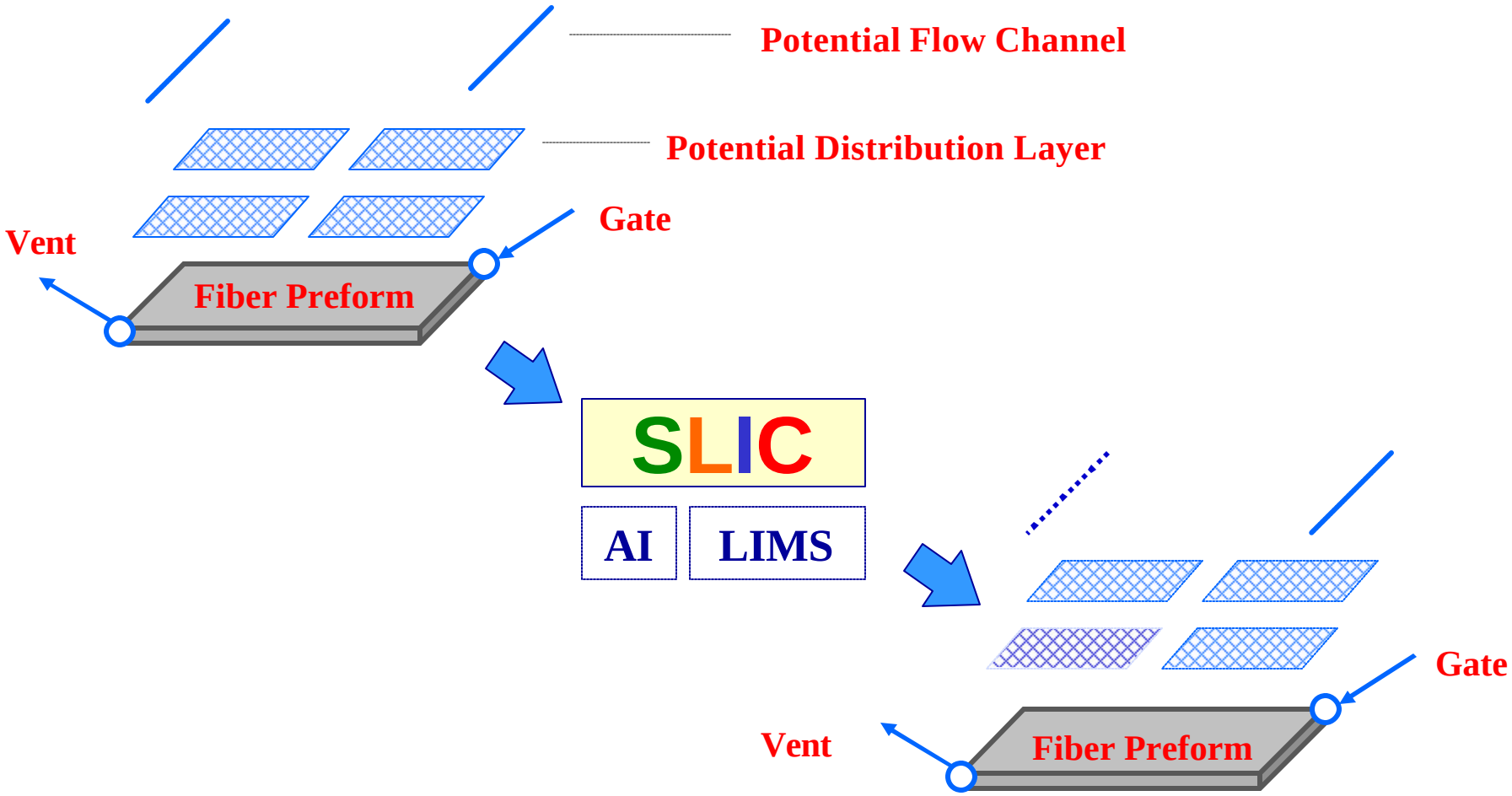
Simulation-Based Approach to Design Distribution Media Lay-Up



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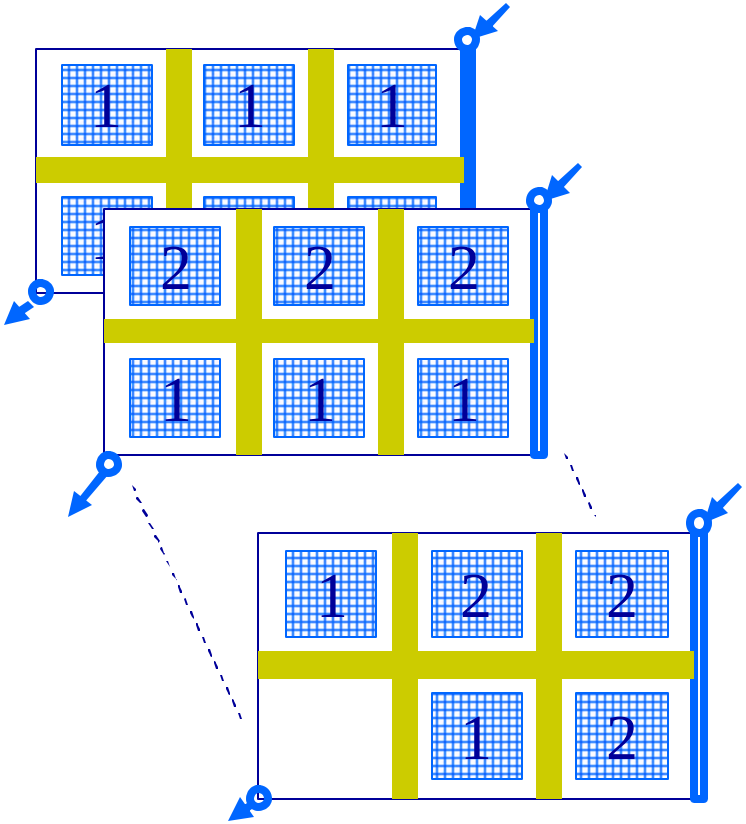
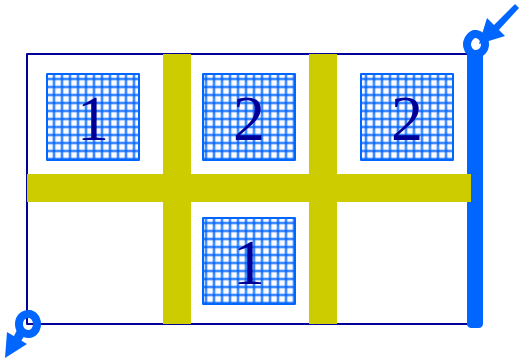
Comparison of Trial and Error Approach with SLIC

Trial and error approach



SLIC



Simulation based approach

Approach	Trial and Error	SLIC
No of experiment	5	1
Dry spot content	0.86%	0.05%
Filling time	12 min	13 min

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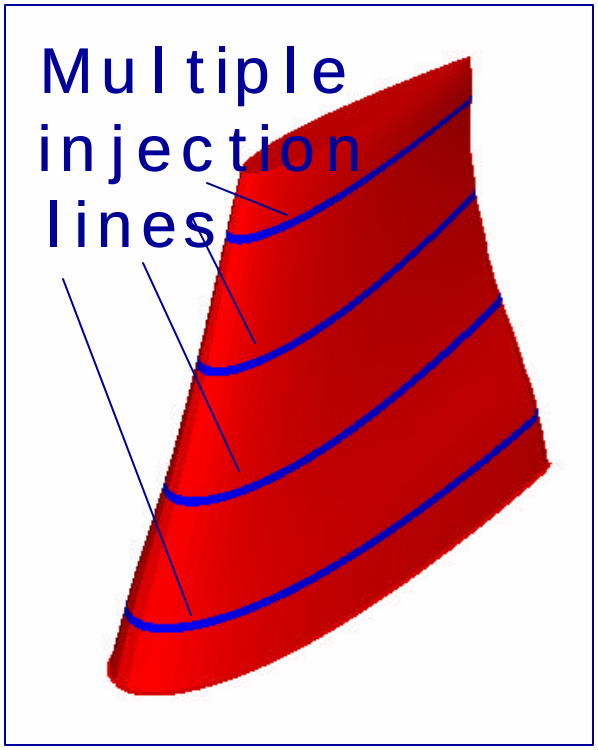
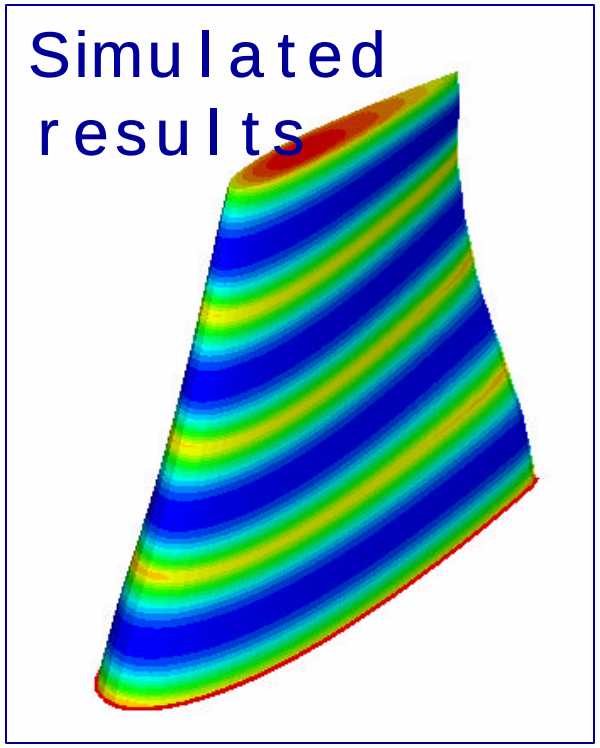
Design of Multiple Injection Locations for Large Parts





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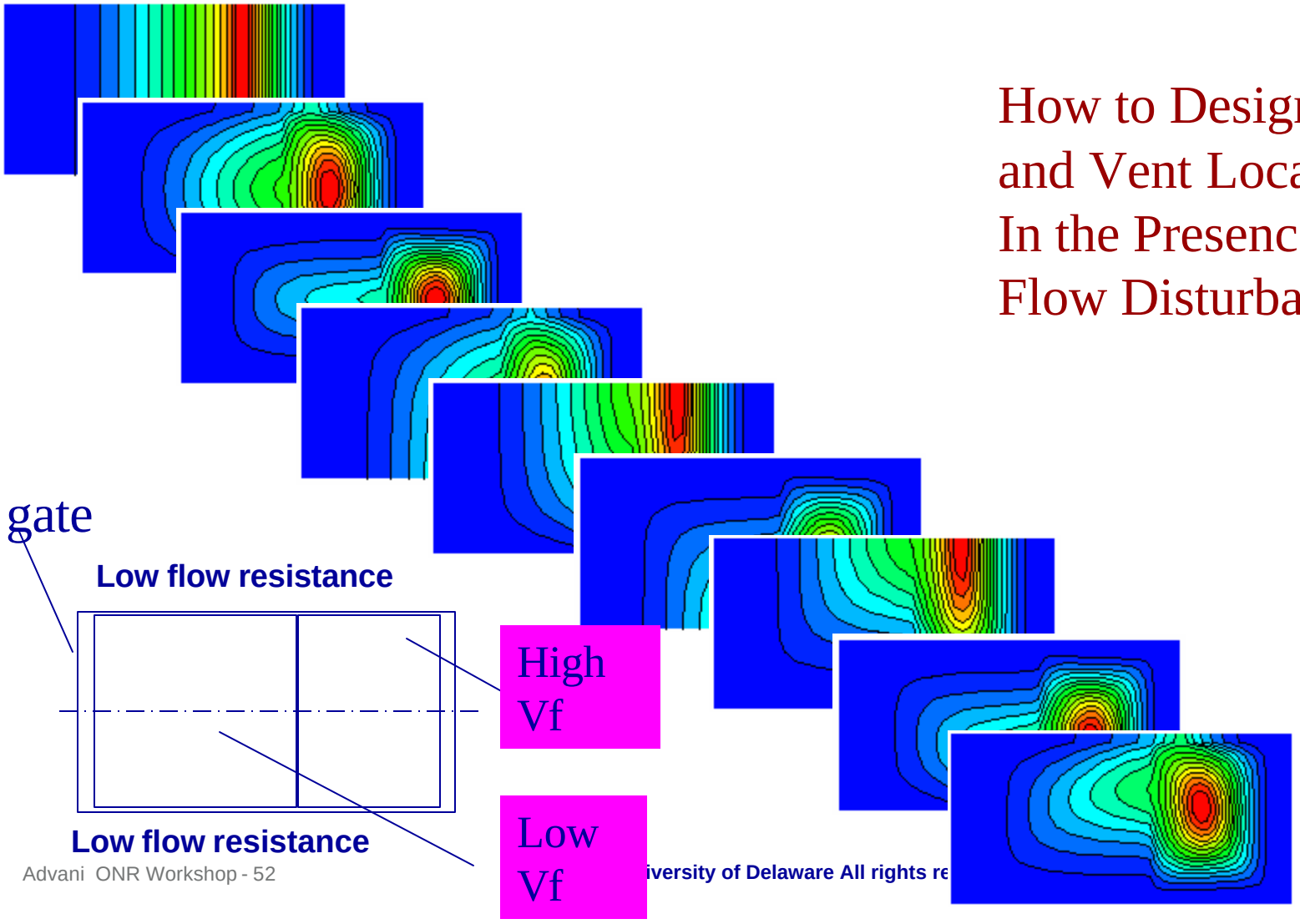
Design of Gates and Vents in the Presence of Flow Disturbances



How to Design Gate and Vent Locations In the Presence of Flow Disturbances?

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Flow Disturbances

Race-tracking is a dramatic flow disturbance that occurs along paths of relatively low flow resistance and will alter the flow front advancement.

Race-tracking does vary from one experiment to next. This variation mainly results from the uncertainties associated with the cutting and placement of the preform in the mold.

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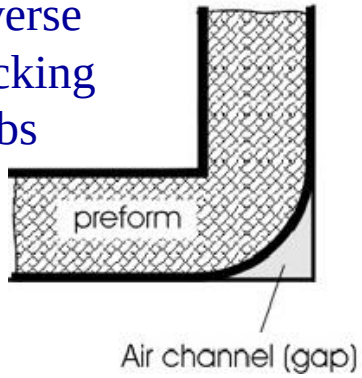
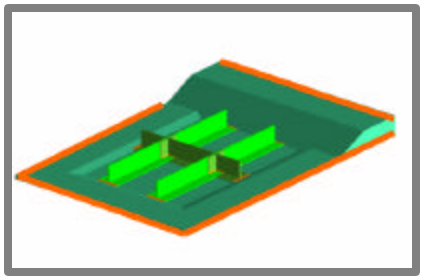
Race-Tracking

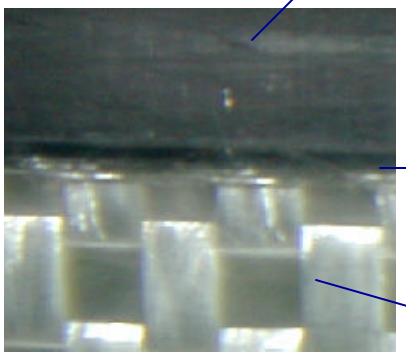
Race-tracking is omnipresent :

Transverse racetracking in ribs

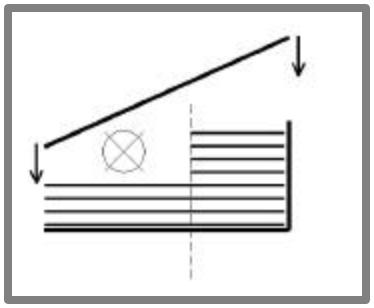




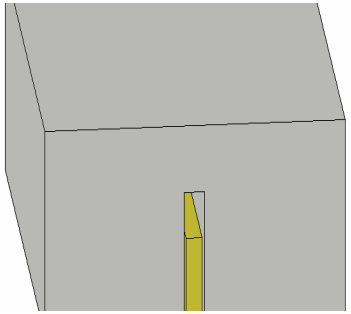
Racetracking along mold walls



Transverse racetracking in tapered regions



Ribs cut too short



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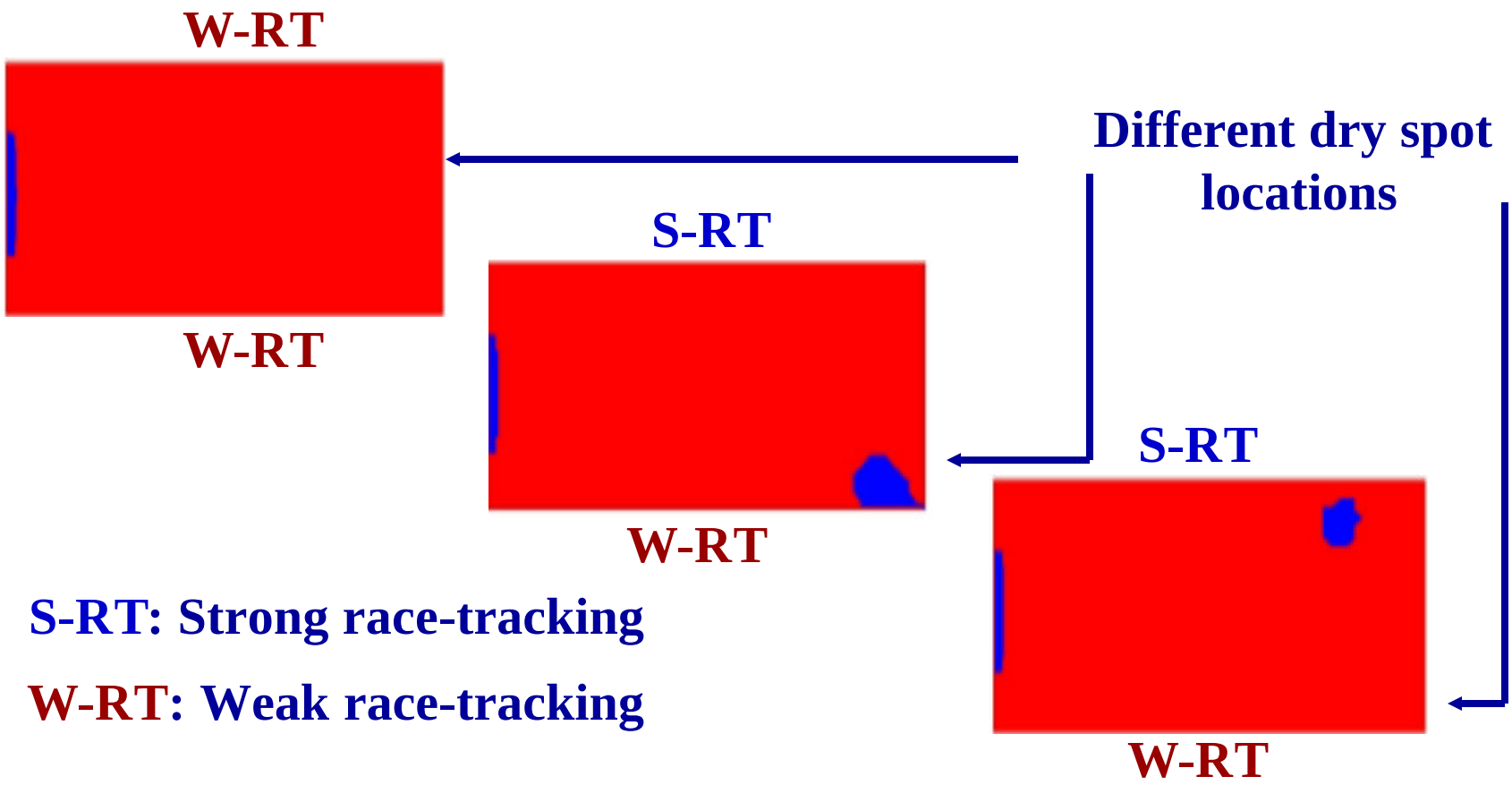
Influence of Race-tracking Strength on Flow Behavior

Different race-tracking strengths will result in different locations for the last region to be filled during each injection



S-RT: Strong race-tracking

W-RT: Weak race-tracking

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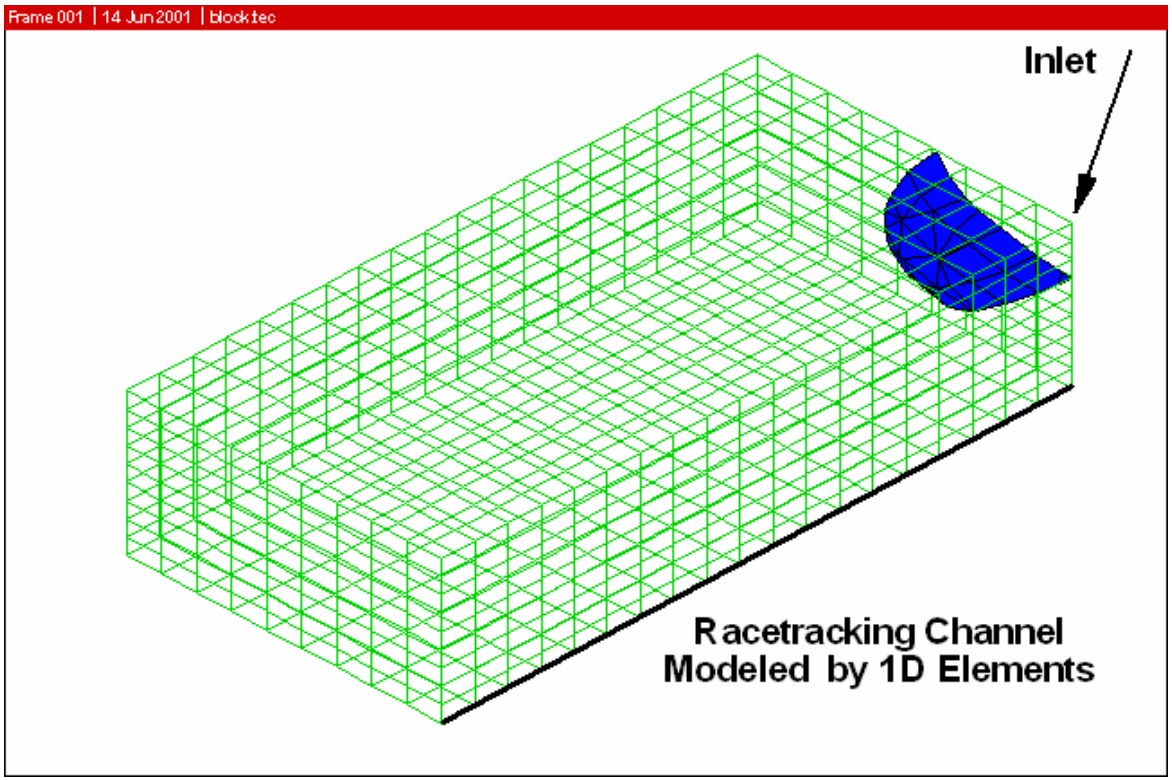
Race Tracking in 3-D Flow

How the race tracking will influence the flow in 3D is not intuitively obvious



2-D flow front surface shown

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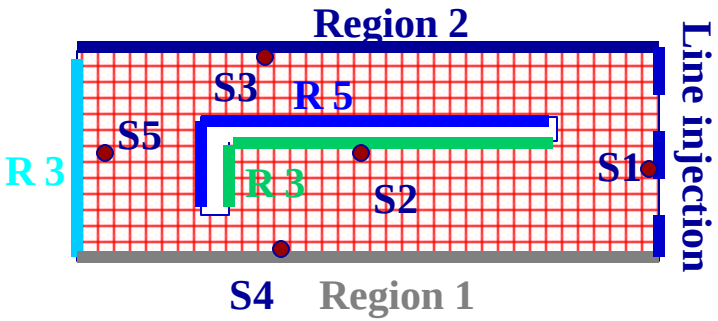
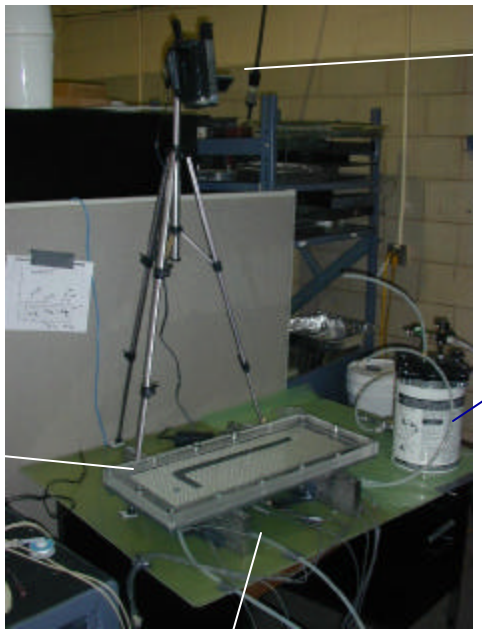
Race-Tracking Is Not Repeatable

- **More than fifty experiments were repeated to characterize race-tracking to illustrate the variability of the process. (5 different operators conducted 10 experiments each). A, B, C and D cut preforms by hands, E used a laser cutter**



The arrival times of the resin at each sensor are used to characterize the degree of race-tracking along the 5 regions



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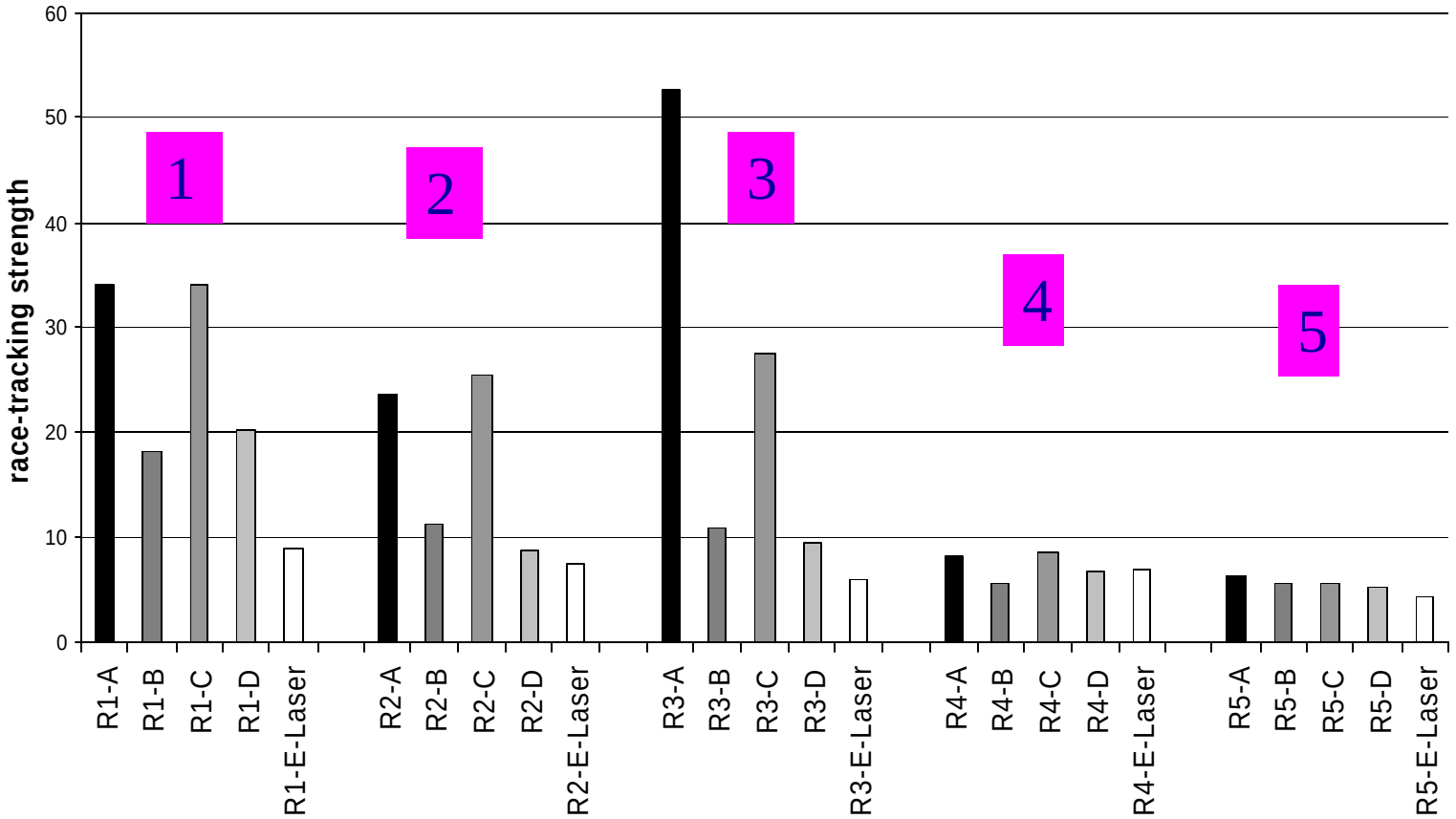
Variation in the Strength of Racetracking

The race-tracking is present and not repeatable on any edge



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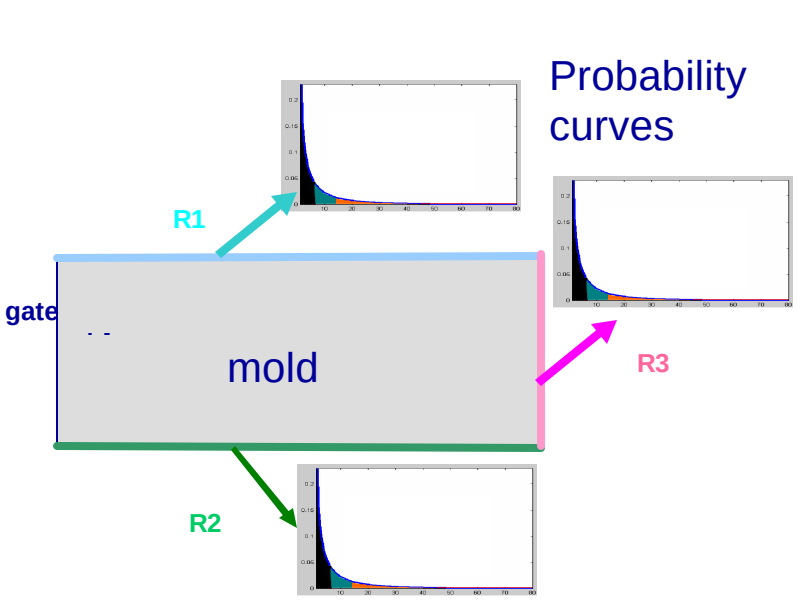
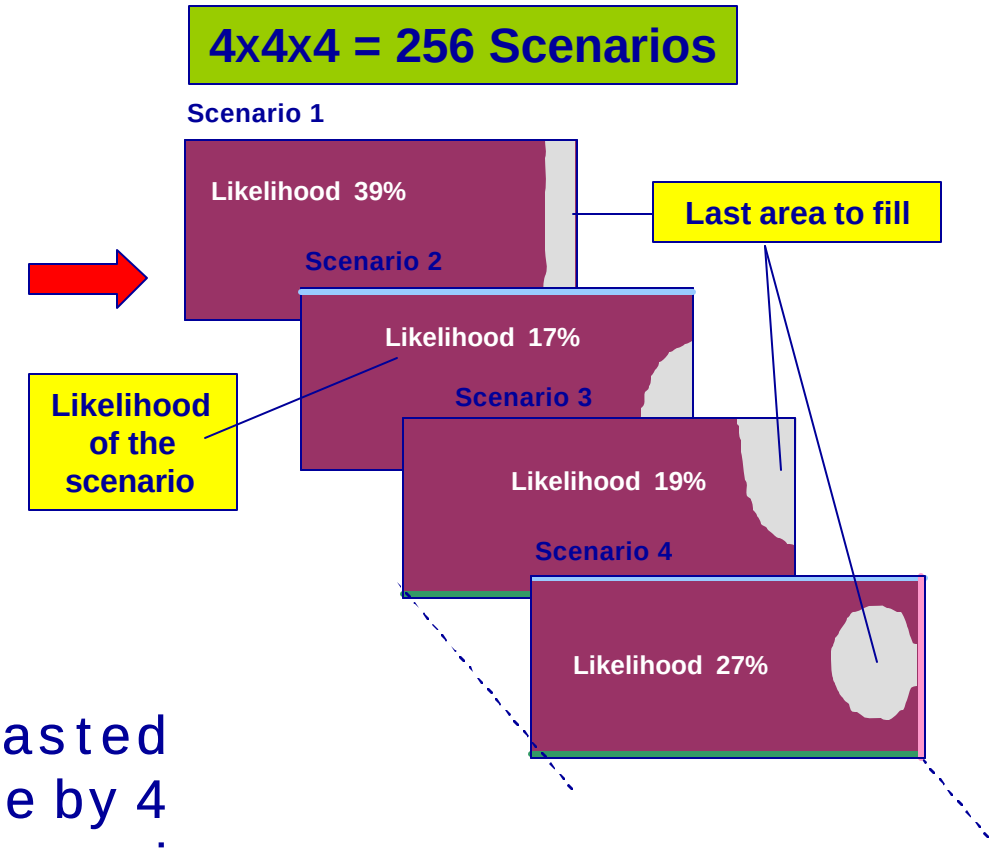
Design Vent Locations with Racetracking Forecast





Each probability curve forecasted for an edge. Represented here by 4 discrete values. Hence the scenarios possible will be $4x4x4 = 4^3$.

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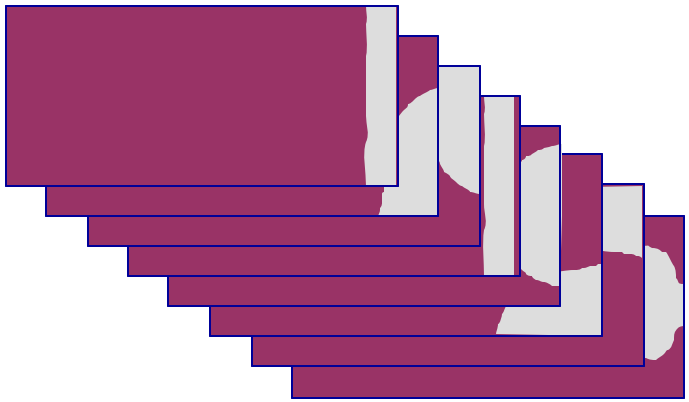
Vent Optimization

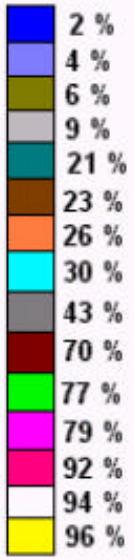
1. **Superimpose all scenarios**



A COMBINATORIAL SEARCH algorithm is developed to find optimal vent locations

Areas with higher % values are more likely to be filled last, hence they are better locations for vents.

2. **Intersect last filled areas**



The legend shows the likelihood of different colored mold regions becoming a last filled area.

3. **Add the probabilities of scenarios that cover the same region**

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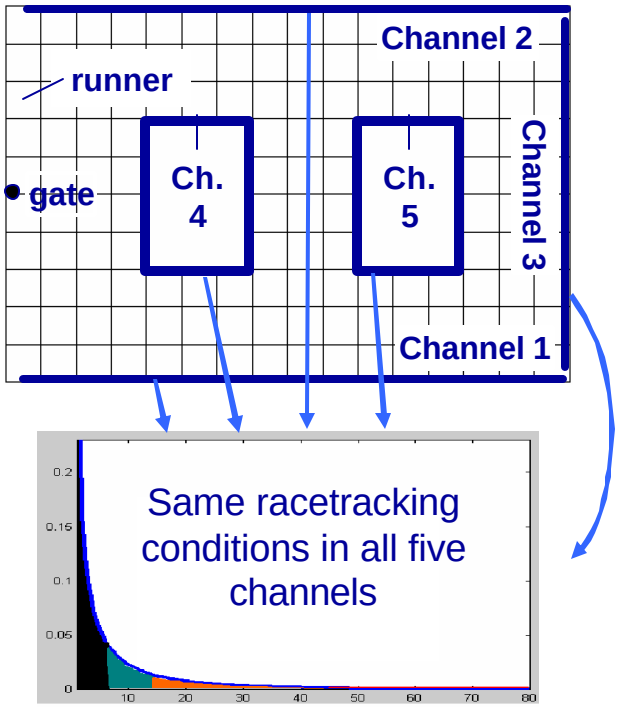
Experience vs. Combinatorial Vent Design

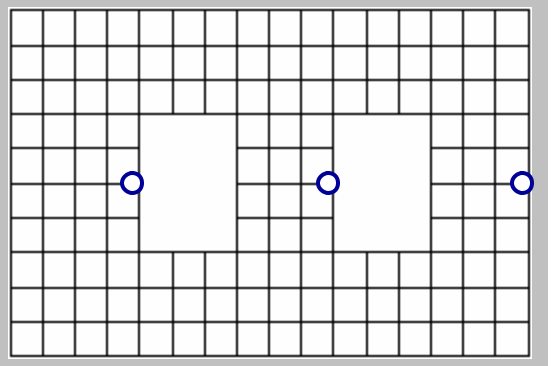
5 racetracking channels are identified



- Racetracking forecast is continuous
- Discretized into four values for each channel
- Hence $4^5 = 1024$ scenarios

Intuition based design

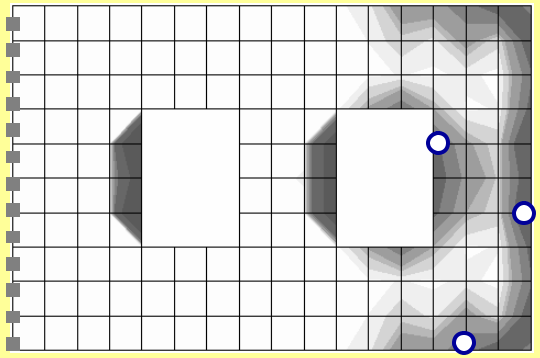
Success Rate: 28%



- Last filled region distribution is found
- Combinatorial Search is conducted to find optimal 3 vent locations

Combinatorial Search

Success Rate: 69%



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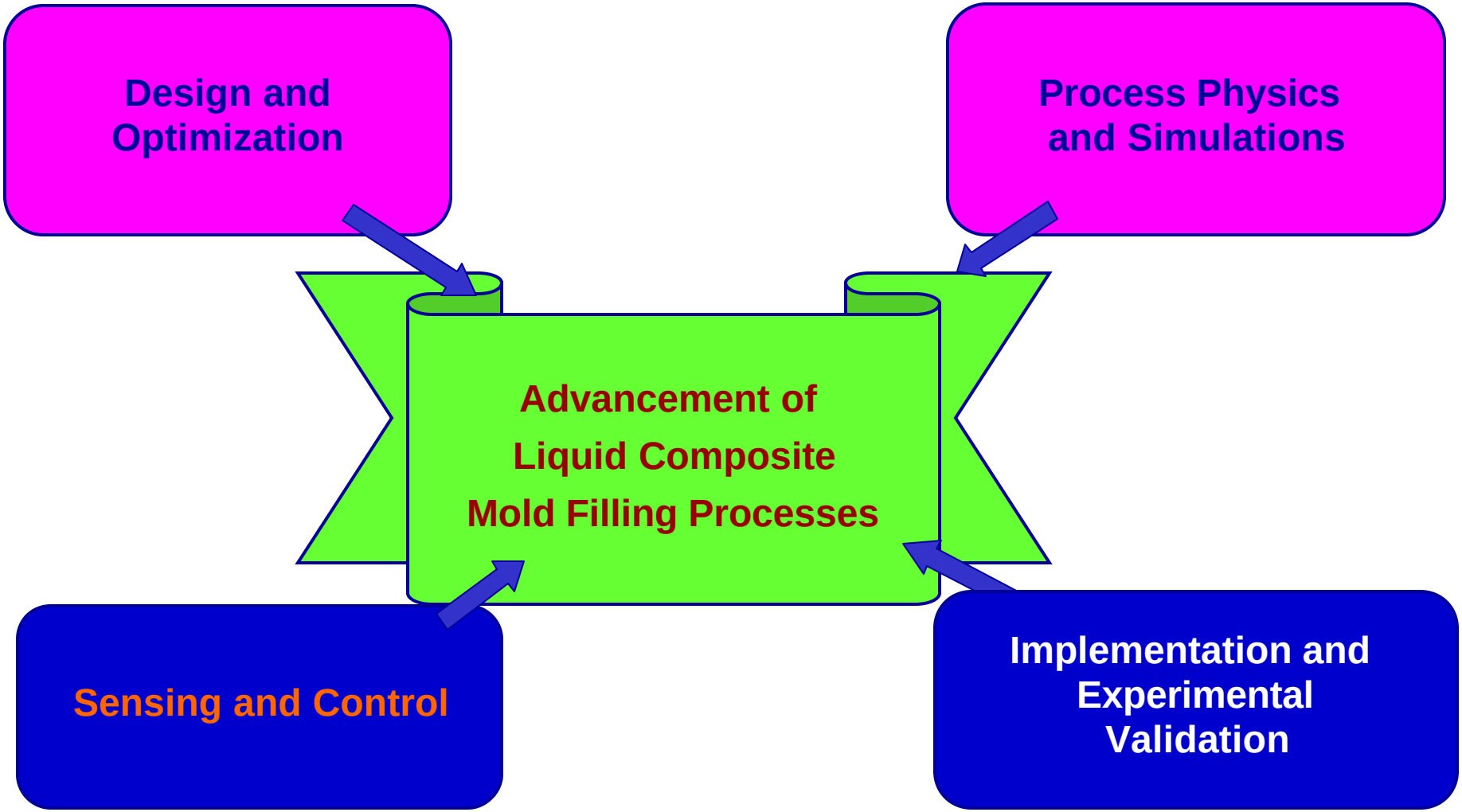
Sensing and Control



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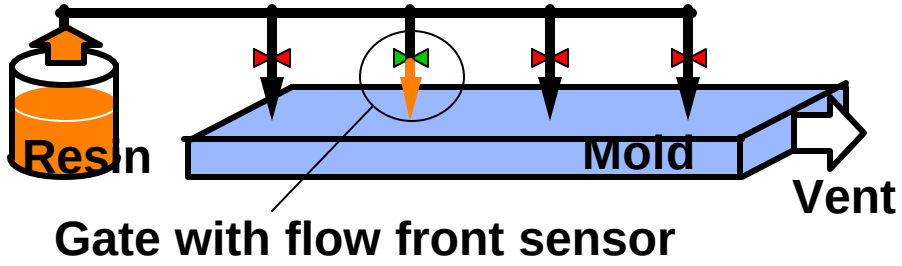
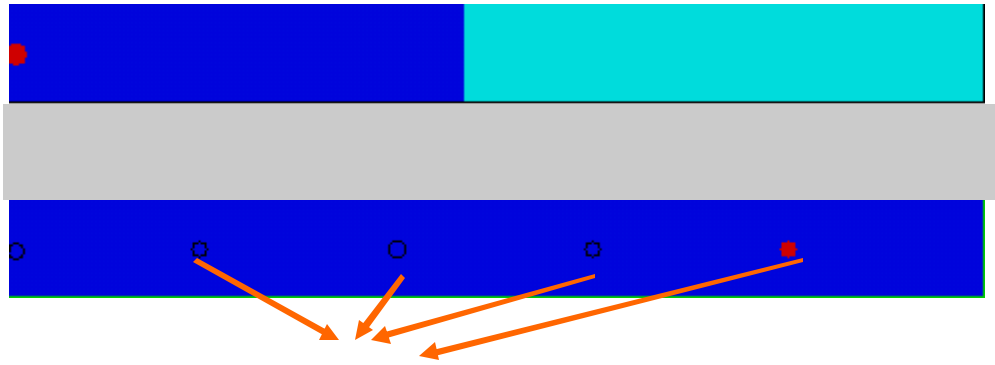
Simulation of Intelligent Injection with Virtual Sensors

T1	ON	OFF	OFF	OFF
T2	OFF	ON	OFF	OFF
T3	OFF	OFF	ON	OFF
T4	OFF	OFF	OFF	ON



Single Gate Injection

Multiple Gates Injection



Auxillary Gates

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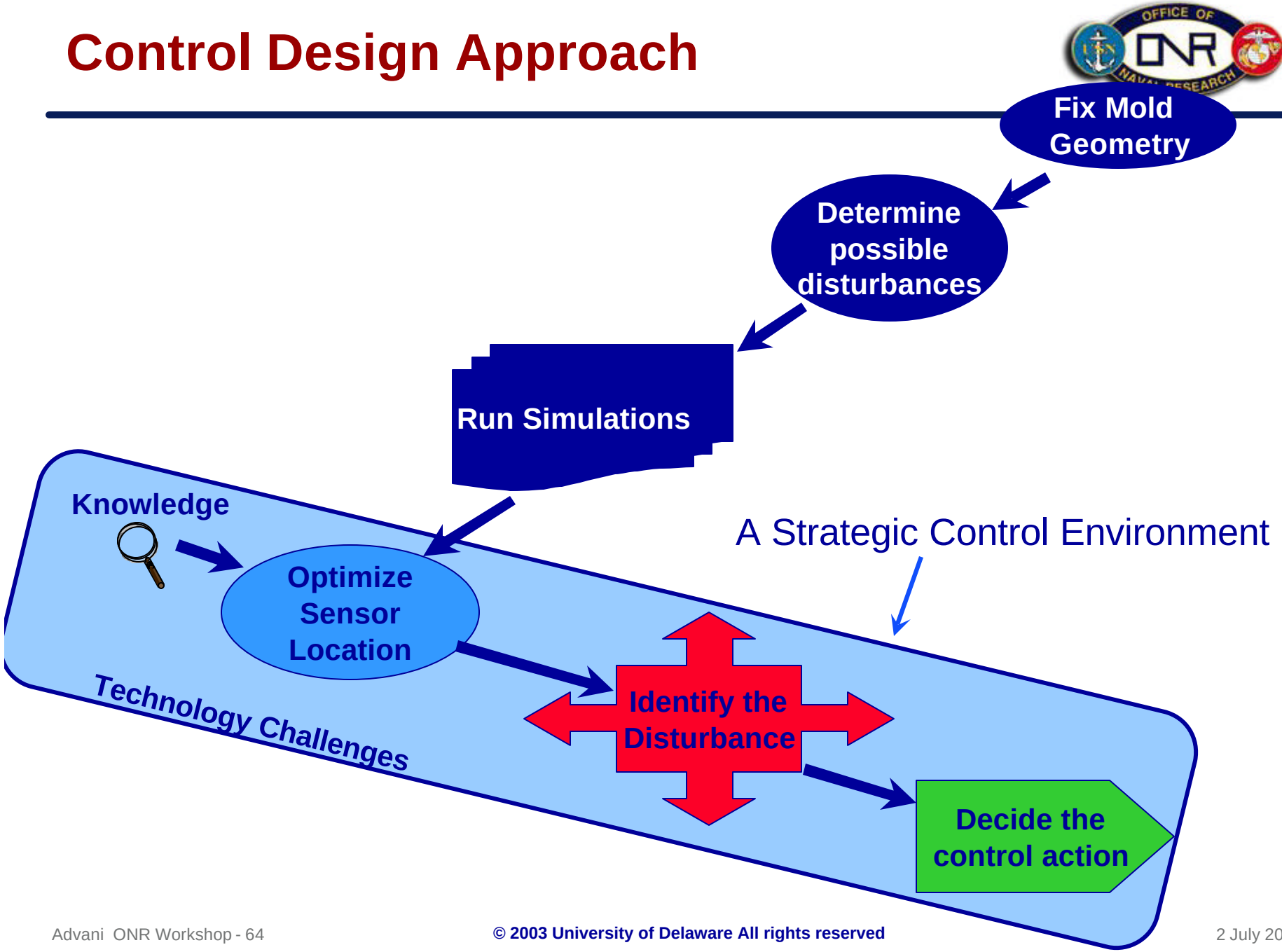
Control Design Approach



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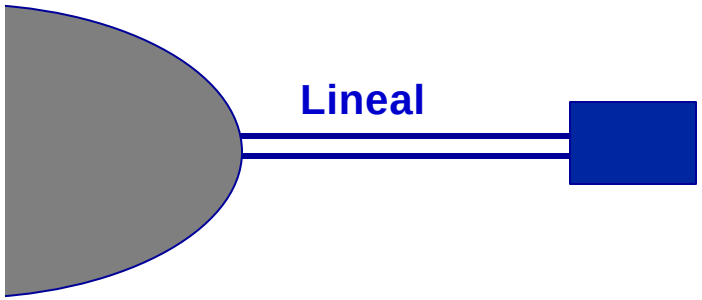
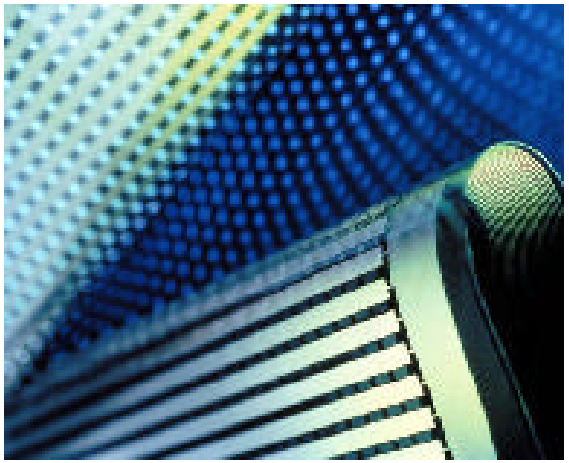
Sensors in Use



Point

Smart (Tekscan)



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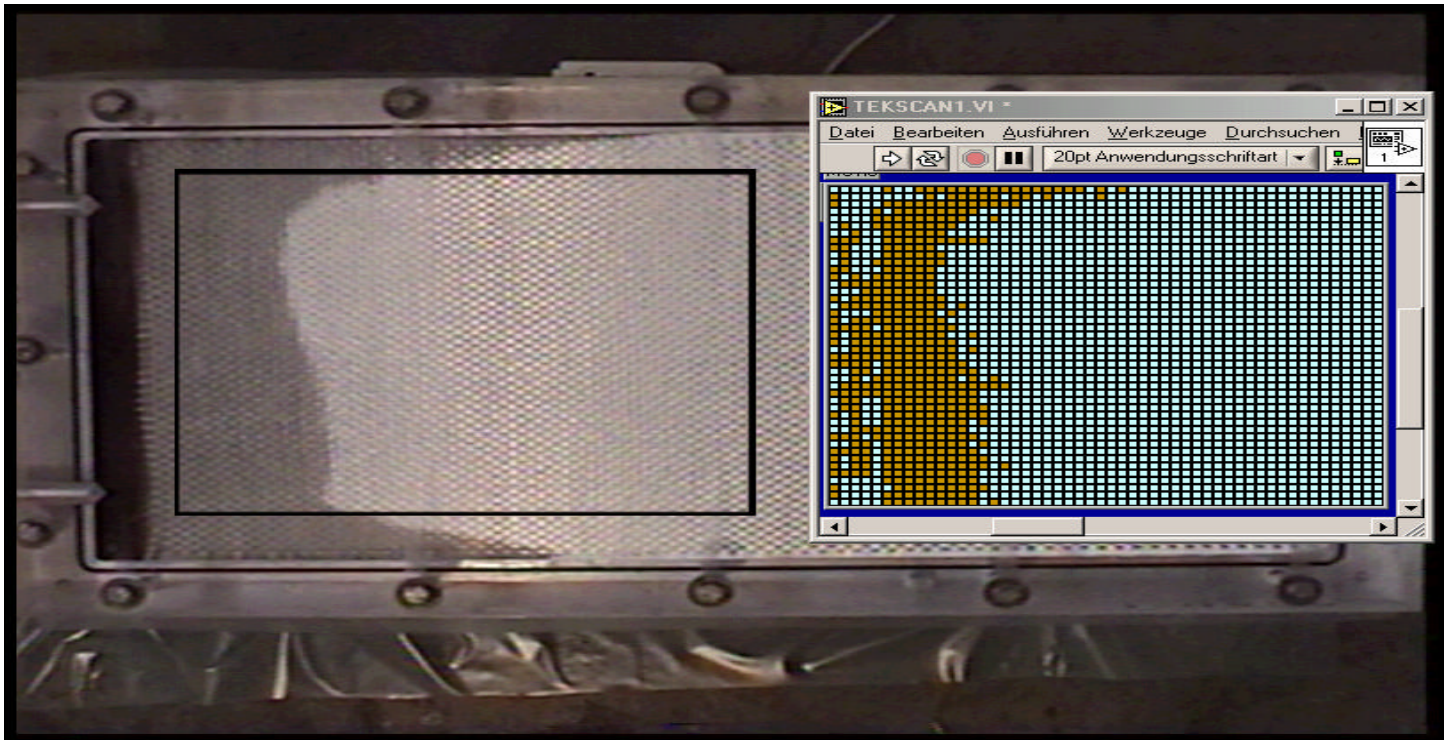
TekScan Sensor for Pressure and Flow Monitoring



Comparison between the RTM-experiment (on the left) and the simulated flow front from the pressure information as obtained by the Tekscan sensor (on the right) at the same time step.

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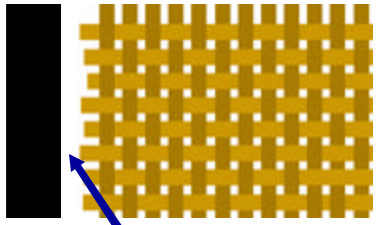
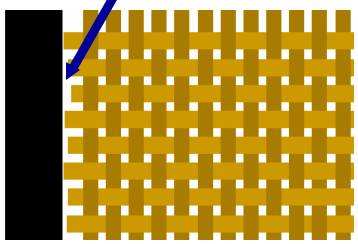
Detection and Characterization of Race-Tracking during Flow

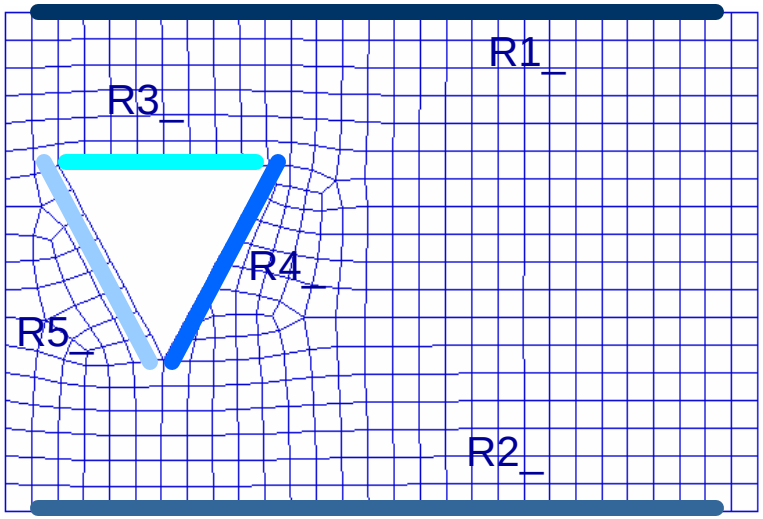


Strong

Weak



×



= 32 Cases

N =2 ; P=5

N levels of race-tracking

p regions where race-tracking is likely to occur

N^p possibilities

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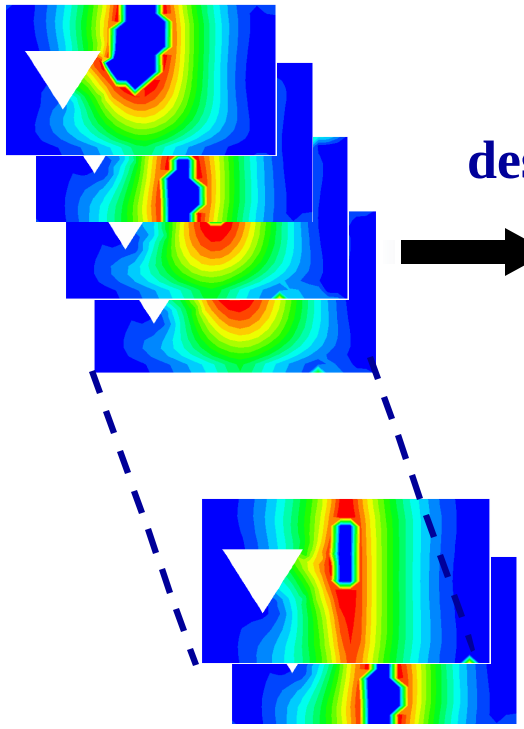
Approach to Create Disturbance Detection and Auxiliary Action Databases

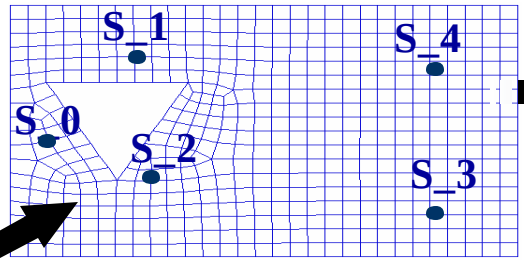
32 disturbance cases



Controller design software

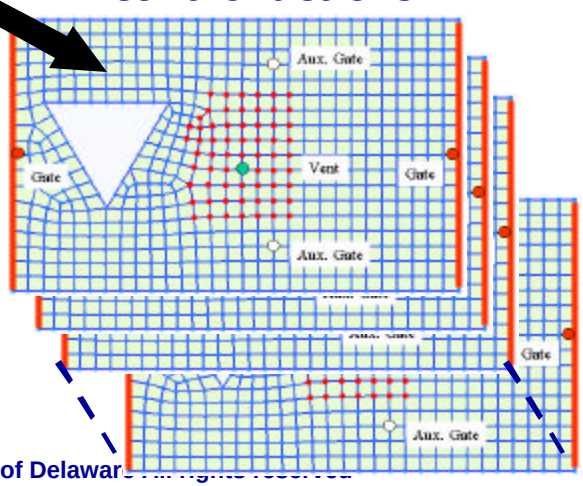
SLIC

Optimized sensor locations that will distinguish between all 32 cases



Detection database to be used on-line for scenario identification

32 customized control actions



Control database to be used on-line for flow re-direction

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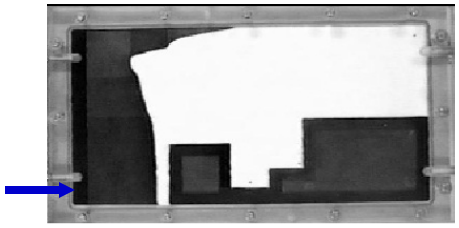
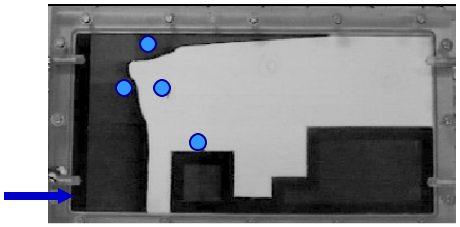
Active Control

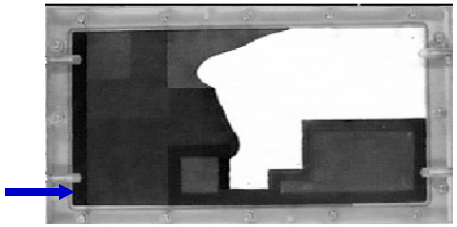
NO ACTIVE CONTROL

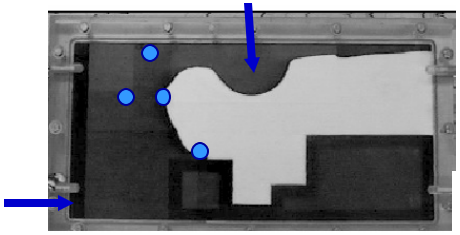
ACTIVE CONTROL



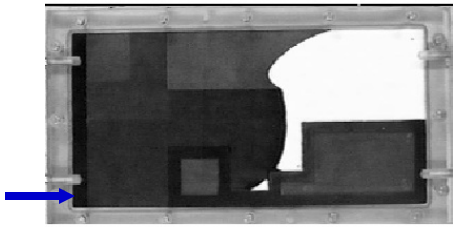


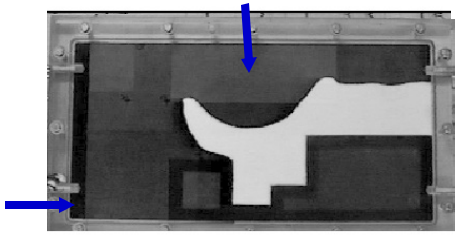
t = 40 s.



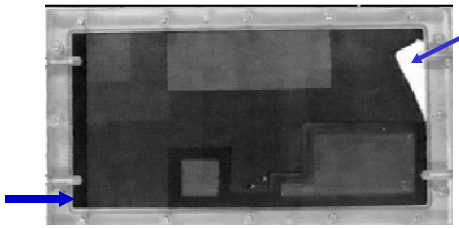


t = 80 s.

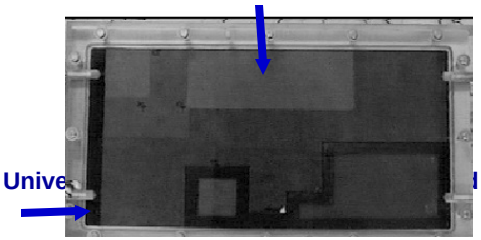




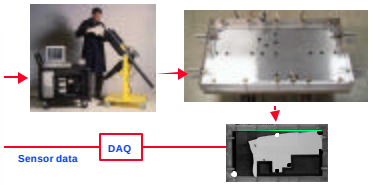
t = 120 s.

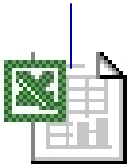


Dry spot

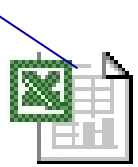


end of exp.





Detection database



Control database

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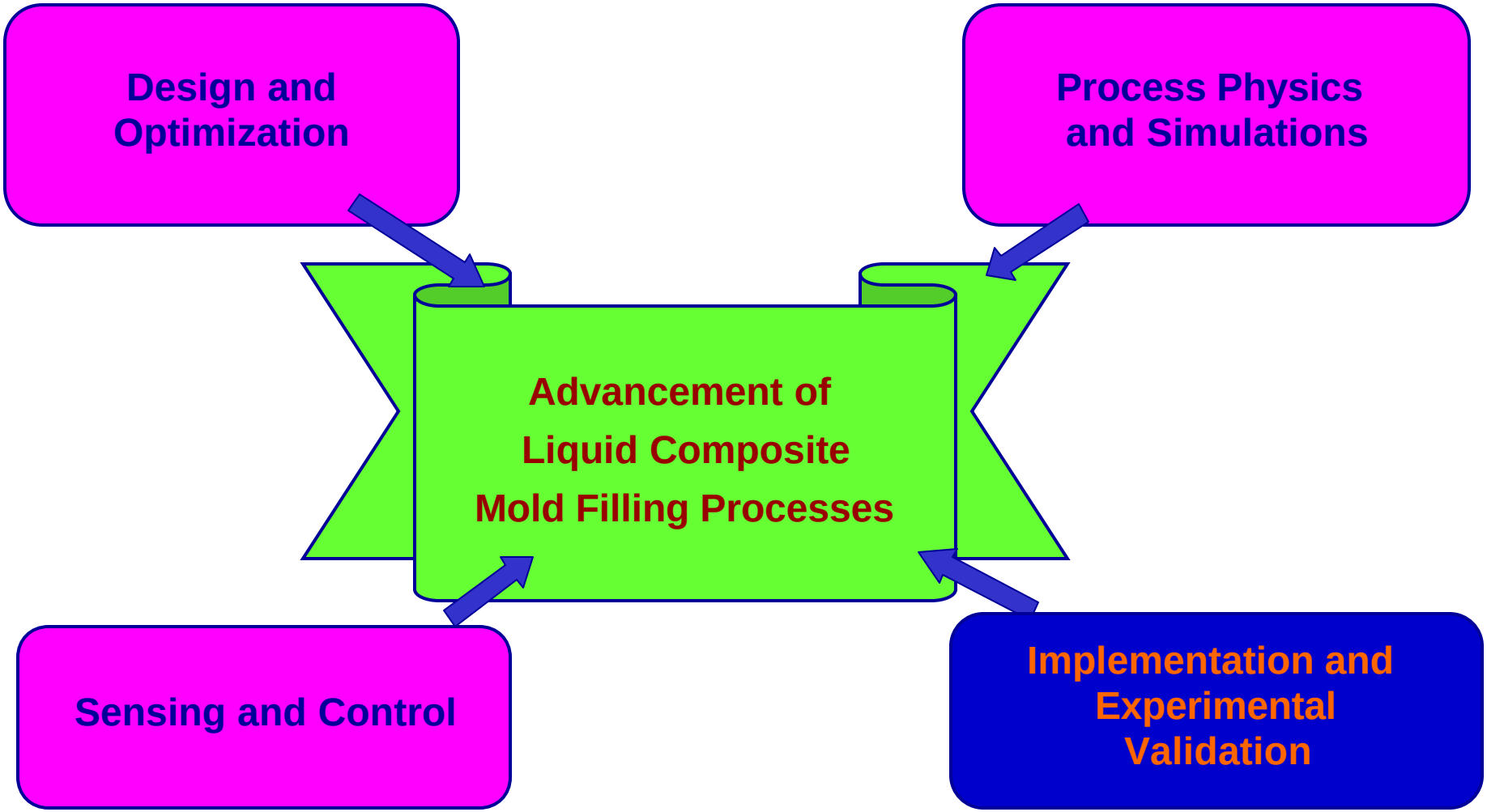
Implementation and Experimental Validation



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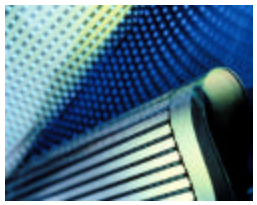
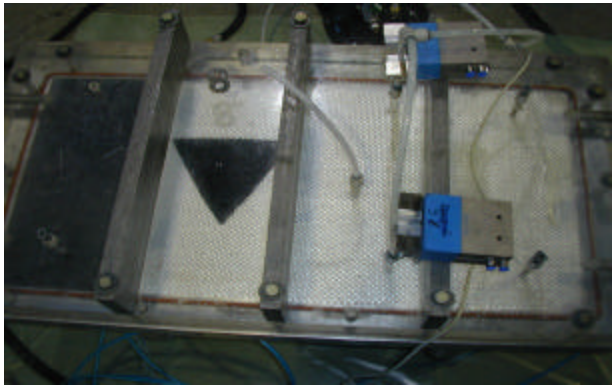
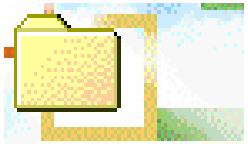
Software and Hardware Integration



Teskscan pressure grid

Flow Sensors





Controller data file.1- Detection and control action databases

Auto RTM

Select a pre-defined scenario that represent the ongoing experiment.

- Implement the customized control action

Injection machine

Actuators

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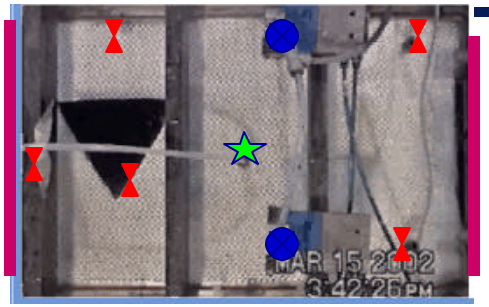
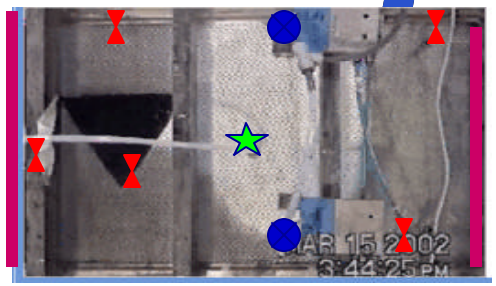
Active Control Methodology





Experimental resin arrival times t1,t2,t3,t4,t5 are reported

Detection database

Scenario 29 is selected

Control action database

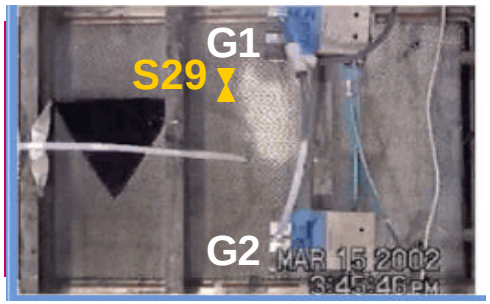
Customized control action for case 29

Initial injection lines

Fixed vent

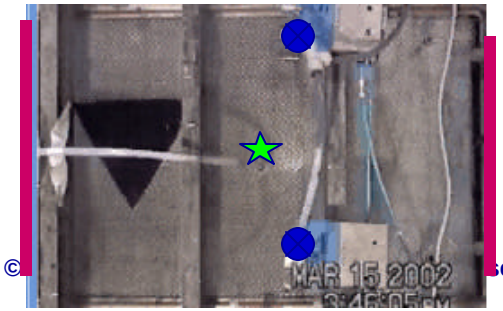
Control gates

Flow sensors for identification



Flow sensors for control action

Control action is to open Gate G1 when resin arrives at the flow sensor S29.



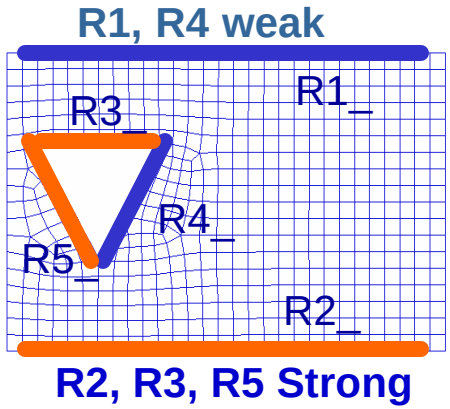
Successful injection

© served

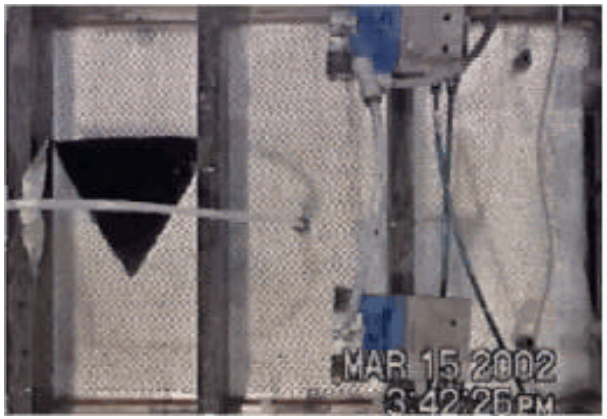
Post Analysis and Flow Simulation Validation

Simulation 29

was selected during injection



Customized control action for the selected disturbance Was automatically implemented



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Result Without Control Action

Case 29 without control action

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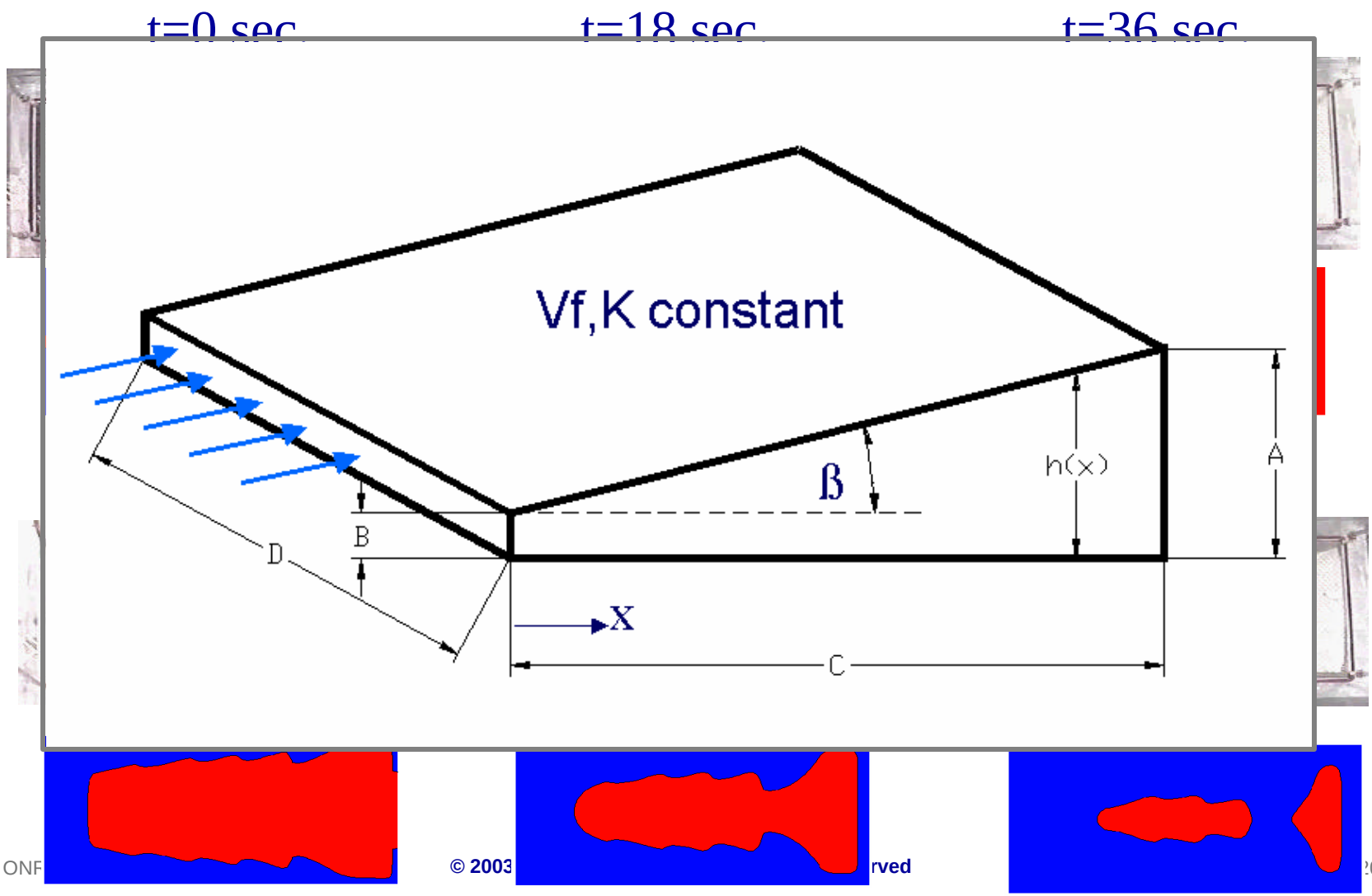
Flow Advancement Verification:Tapered Mold



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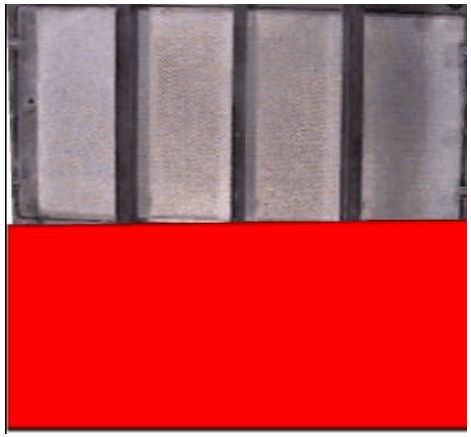
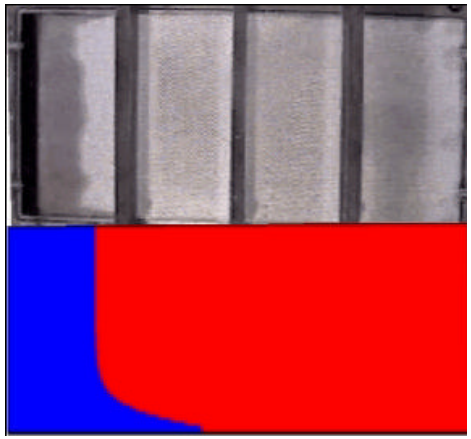
Verification: Race Tracking along Bottom Edge

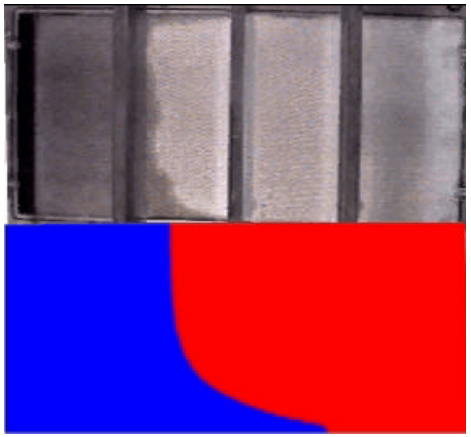
t=0 sec.



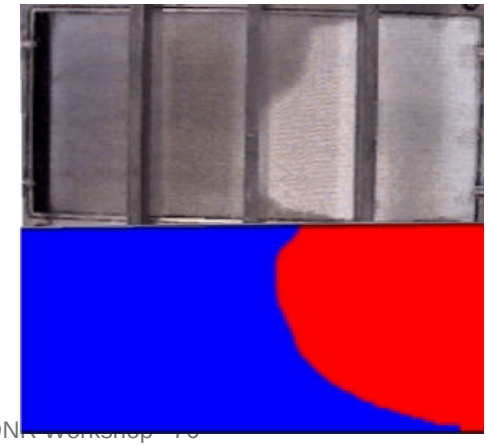
t=30 sec.



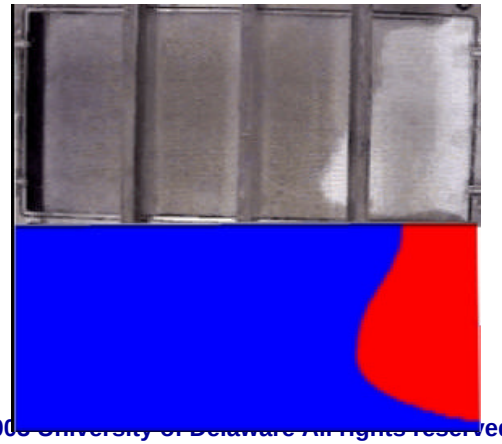
t=60 sec.



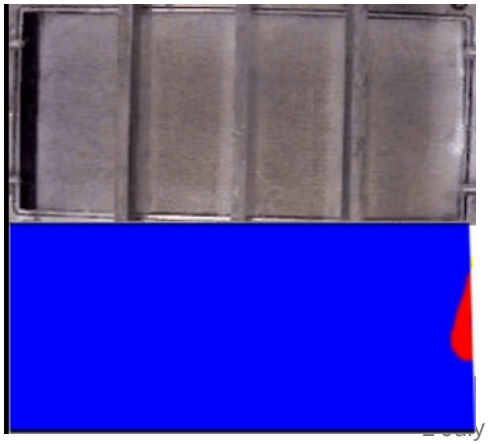
t=90 sec.



t=120 sec.



t=150 sec.



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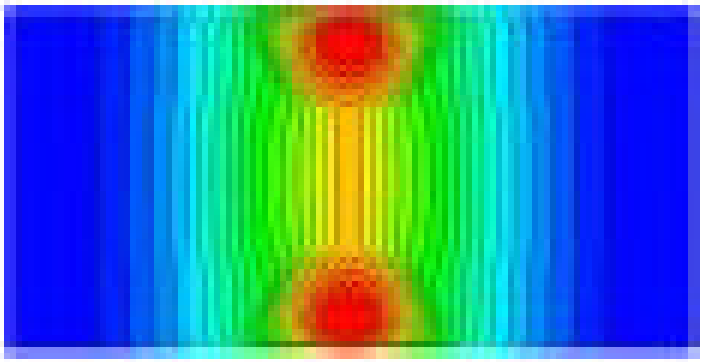
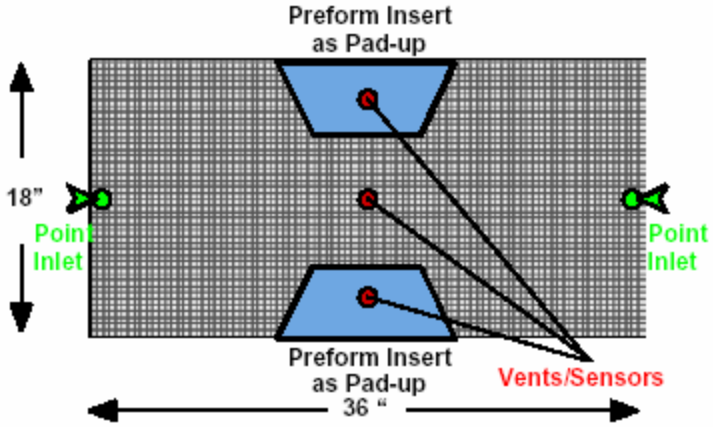
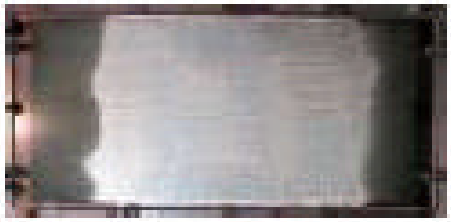
Flow Verification: Bus Mold

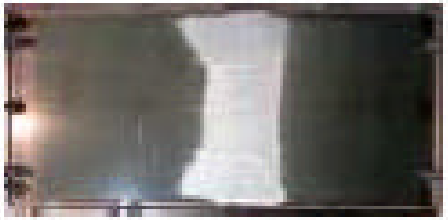


Pad-up Configuration





t =15 s



t =75 s

t = 135 s

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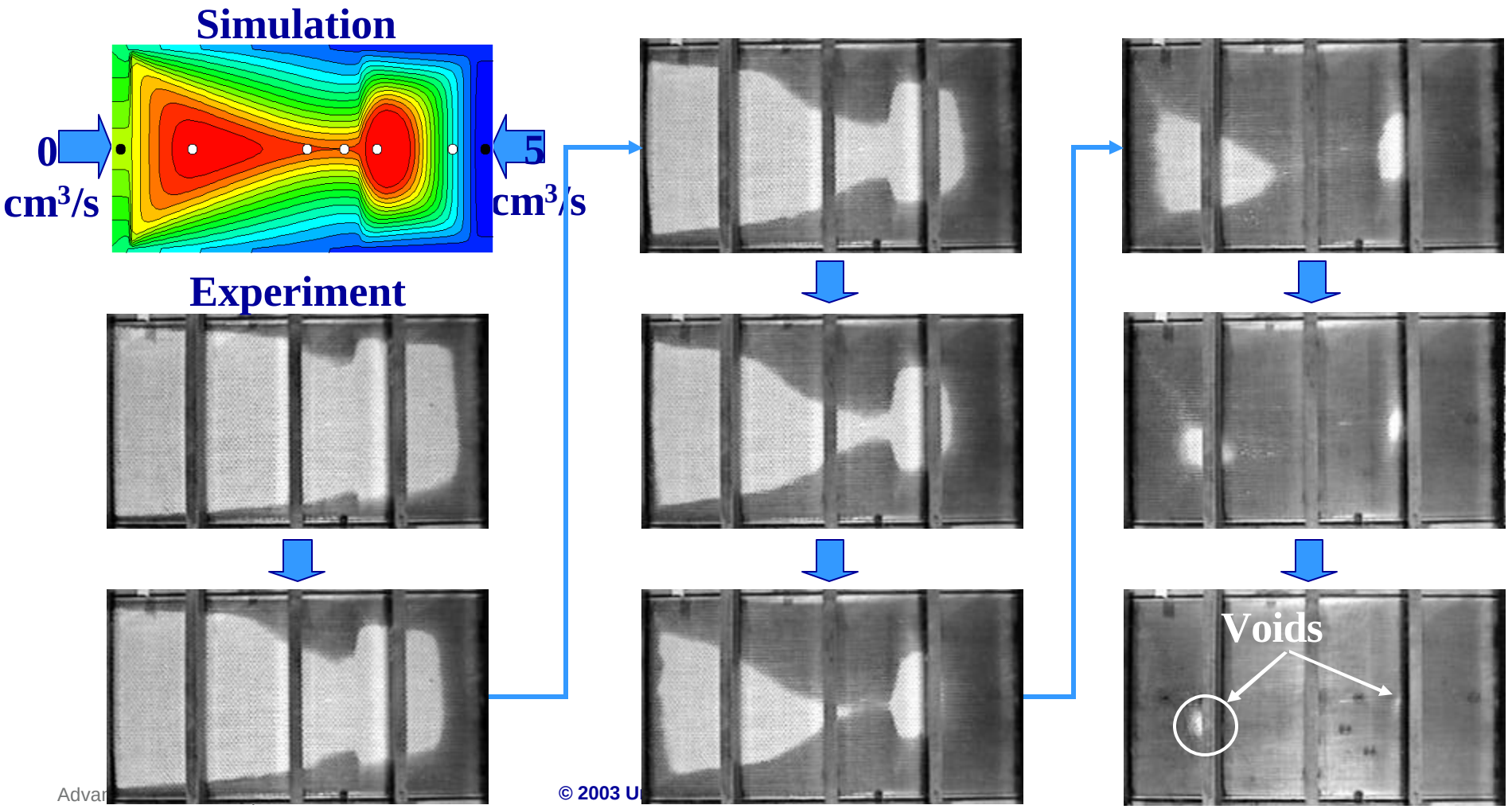
Low Fiber Volume Fraction on the Left



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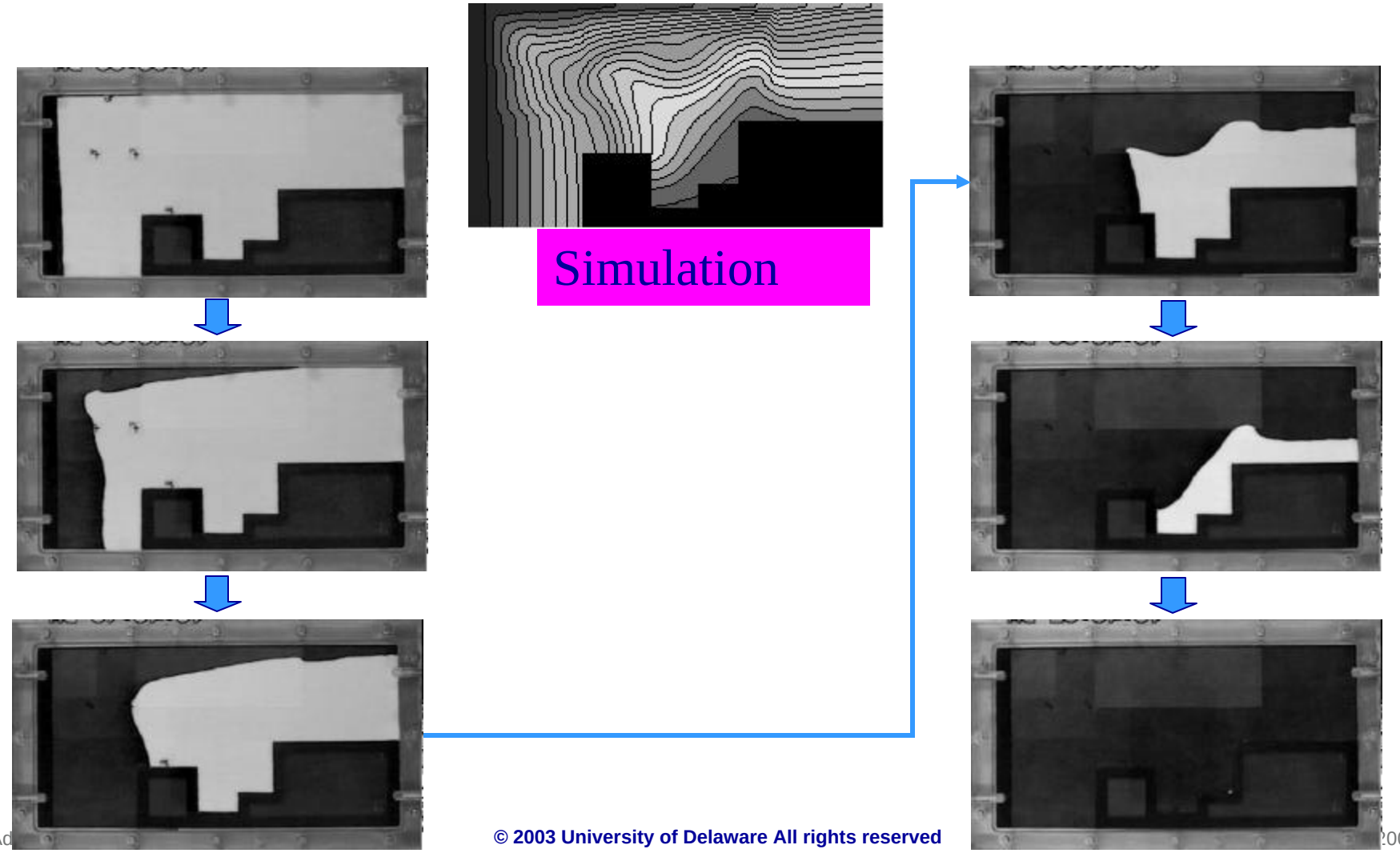
Verification: Changing Fiber Volume Fraction



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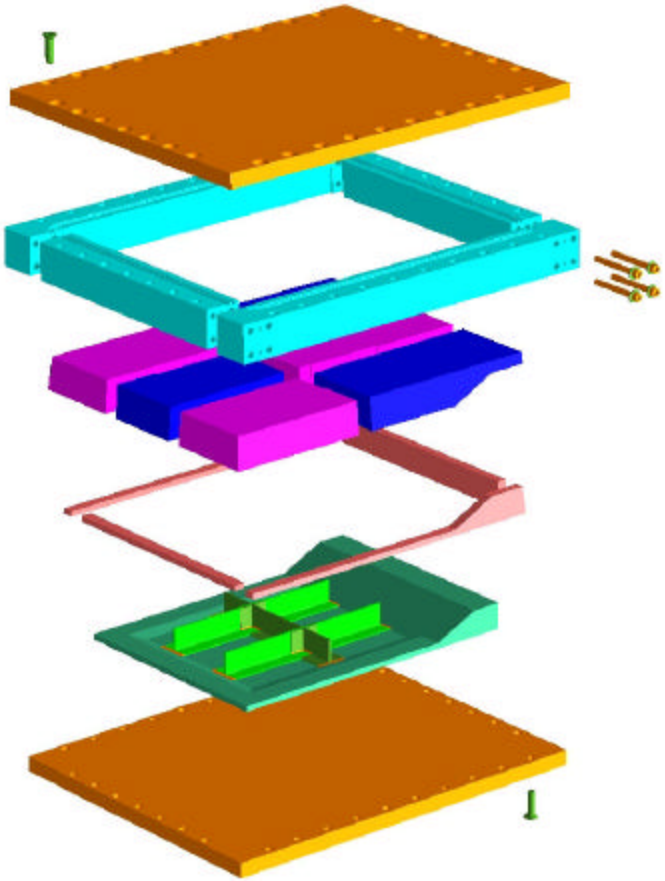
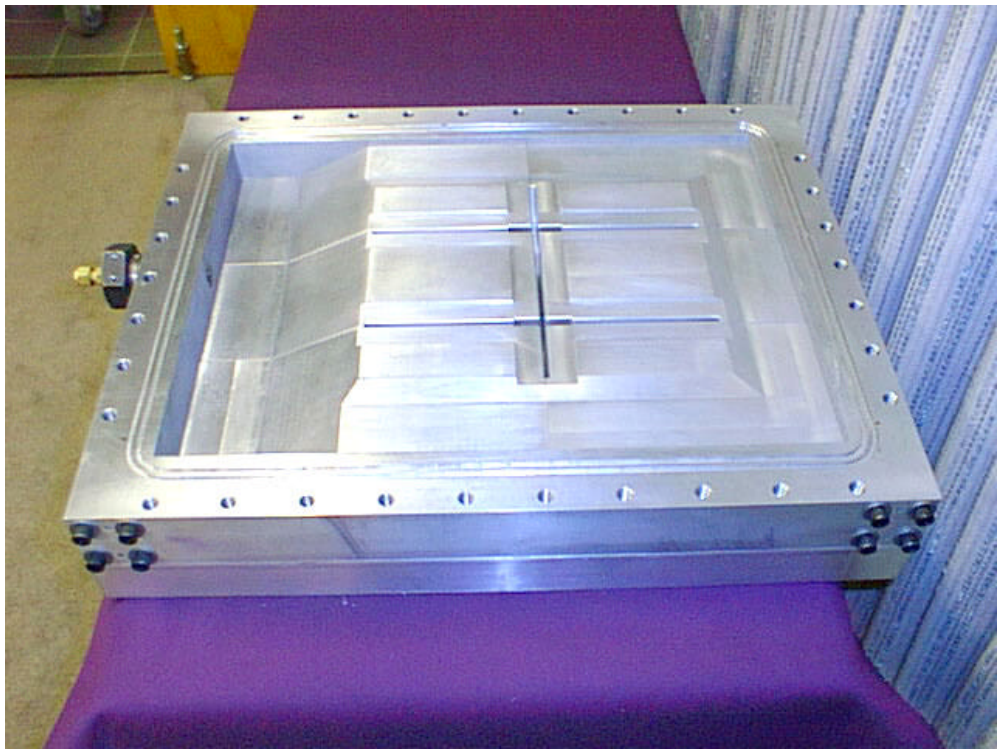
Active Control in a Complex Geometry

Mold Design



Exploded Solid Model



Assembled Lower Mold Platen

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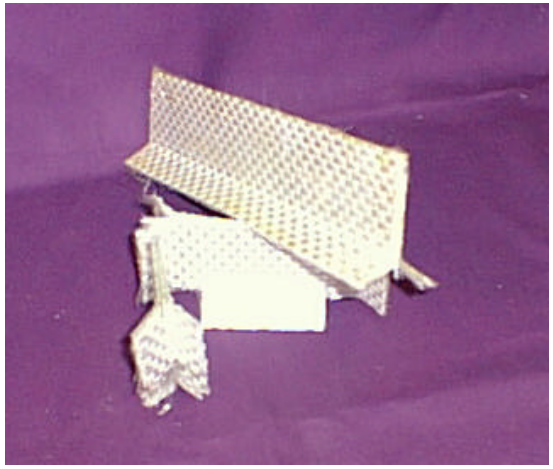
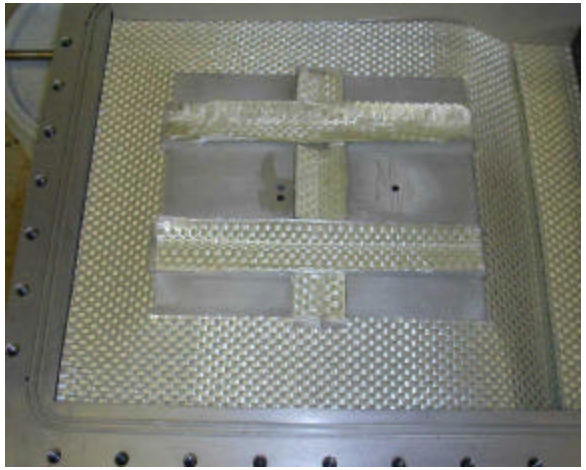
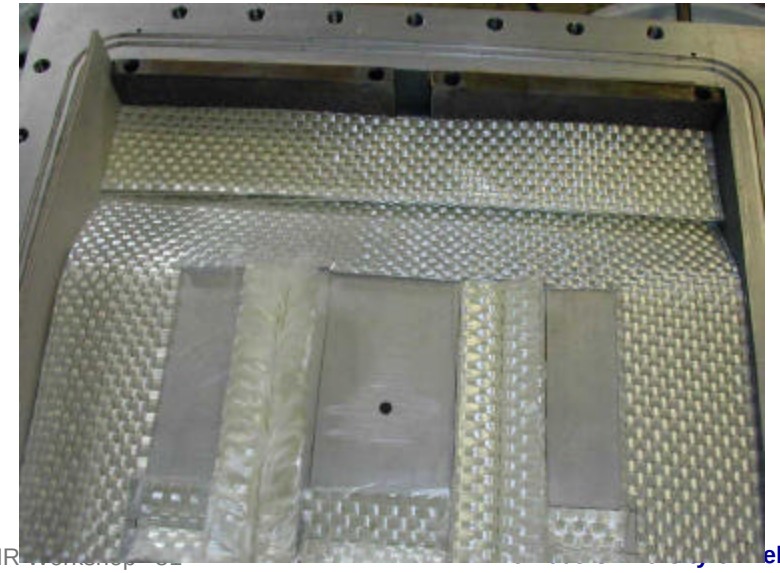
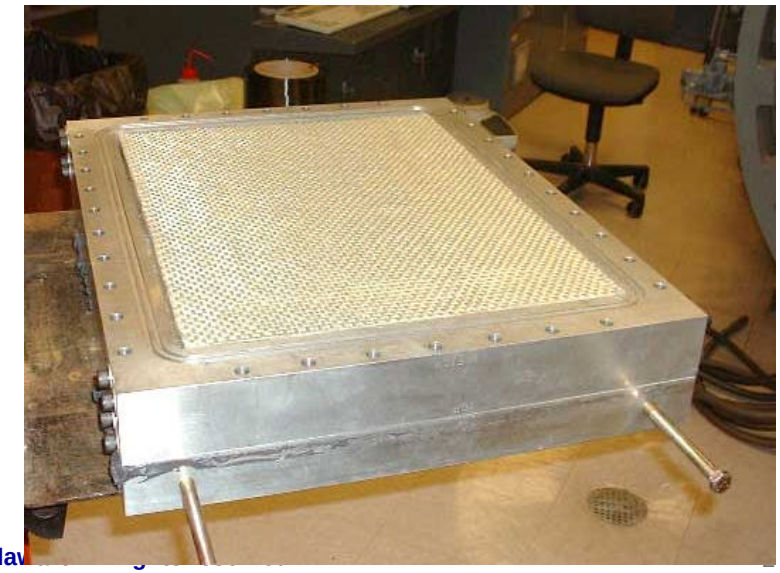
Preform Preparation

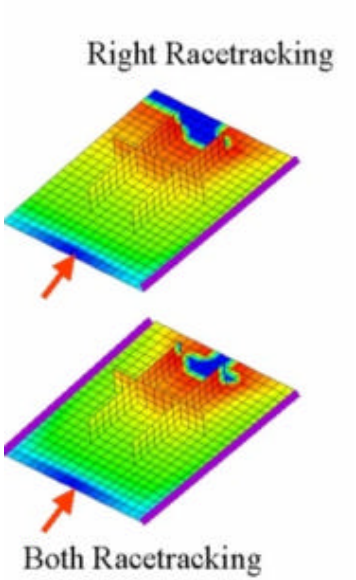


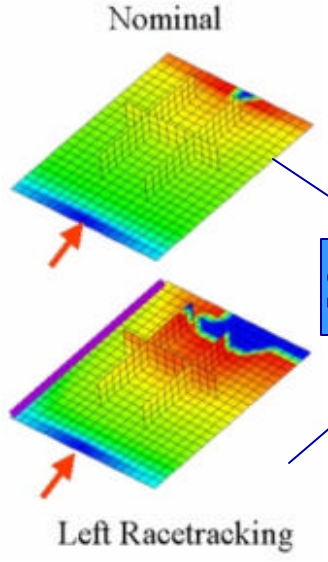






Detection and Control Action





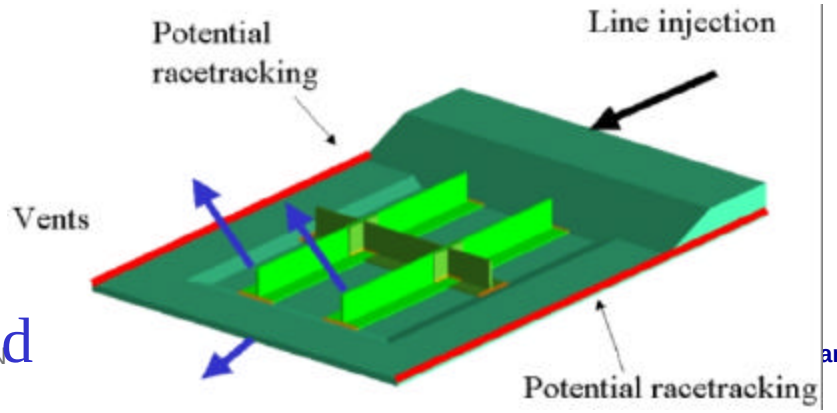
SLIC

Detection database

Control database

Scenarios

Sensor feedback to detect scenario



Mold

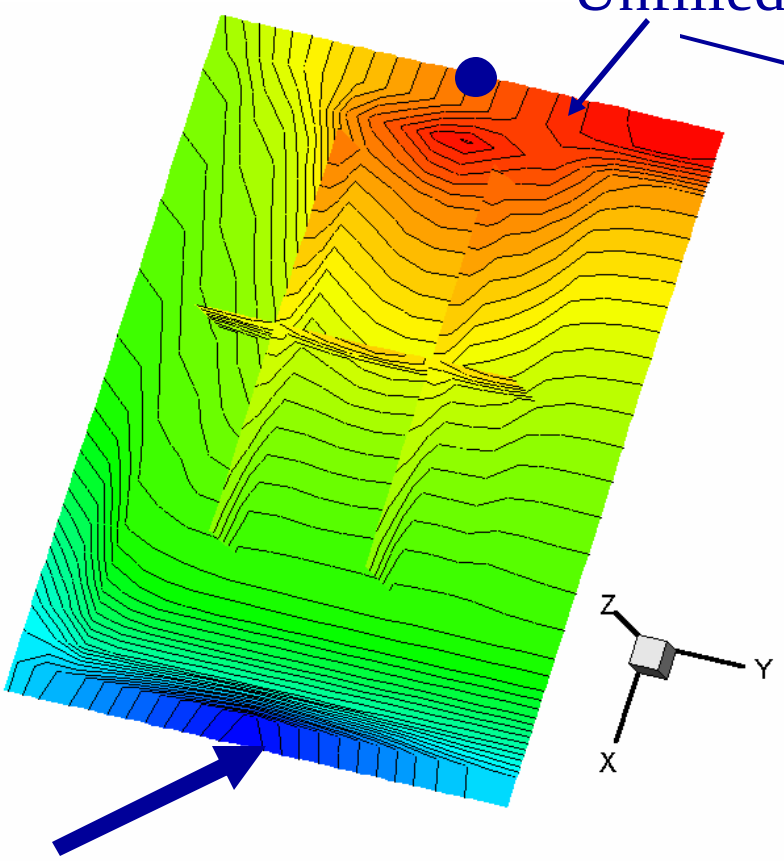
are All

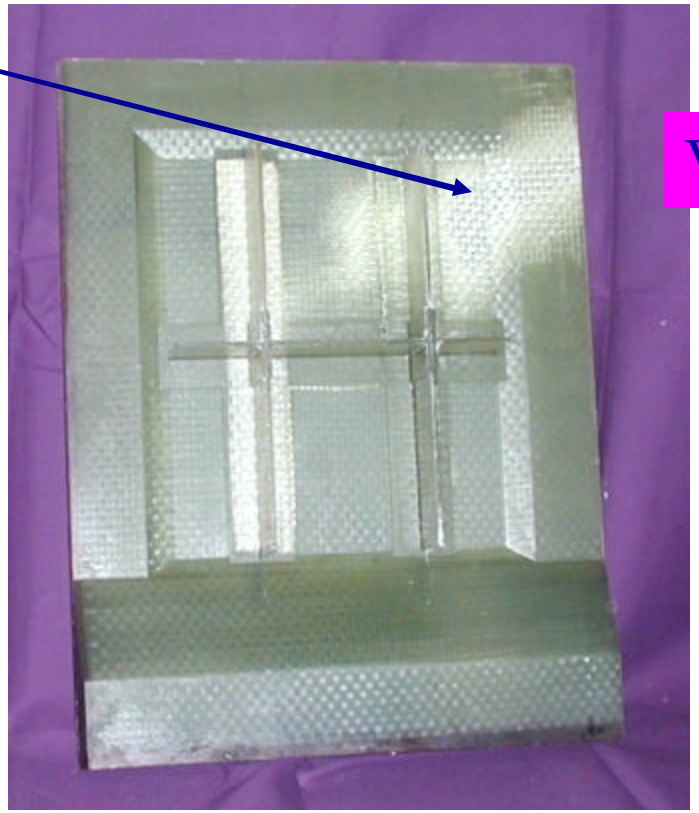
Left Side Racetracking – No Control

Filling Simulation:

Manufactured Part:

Unfilled region





Void

Inject with $Q = Q_0$

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Left Racetracking - Control

Filling Simulation:

Manufactured Part:

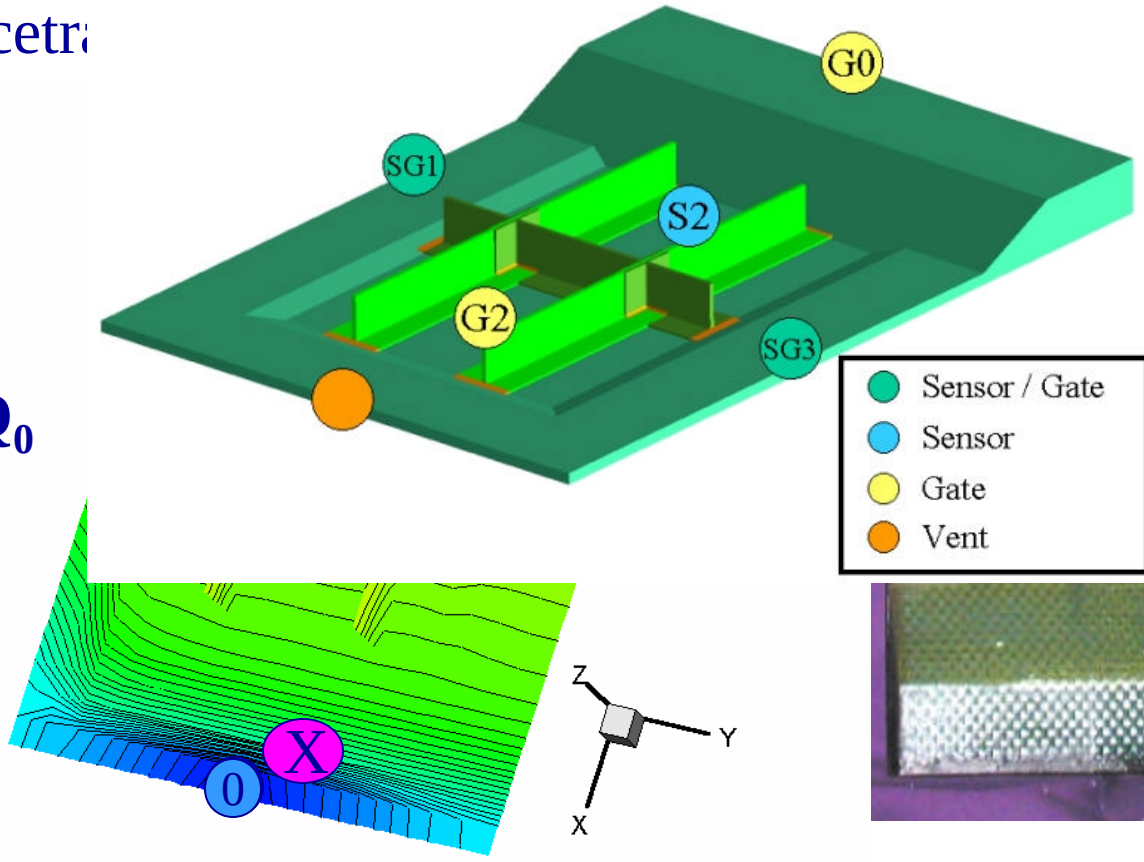
When racetra
inject:

#0: 0.0

#1: $\mathbf{Q_0}$

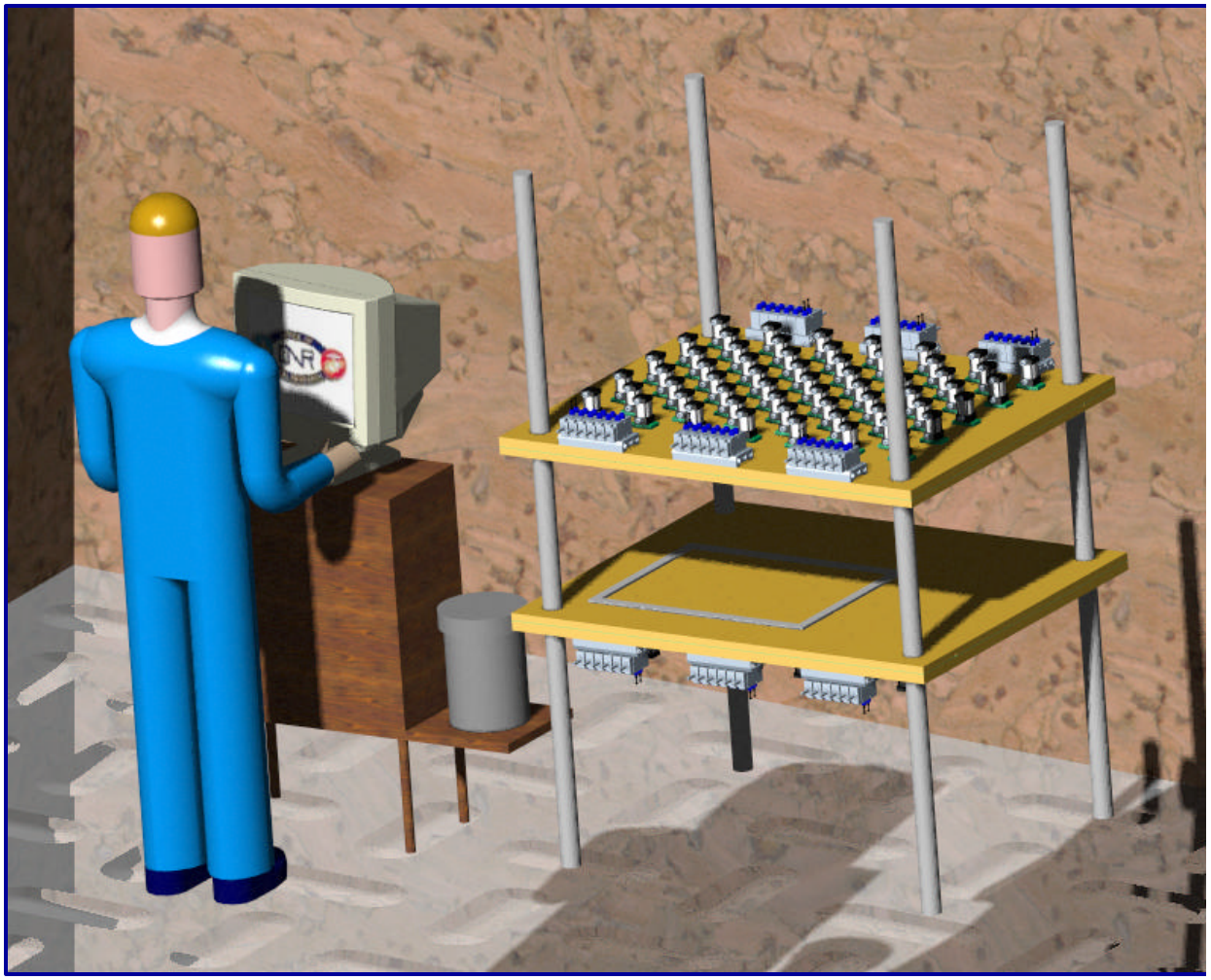
#2: **1/3** $\mathbf{Q_0}$

#3: 0.0



Objective

The objective is to build a modular RTM Workstation that can be used to manufacture various part geometries as well as provide flow control and sensing over the resin filling stage to ensure properly filled parts in the case of flow disturbances.



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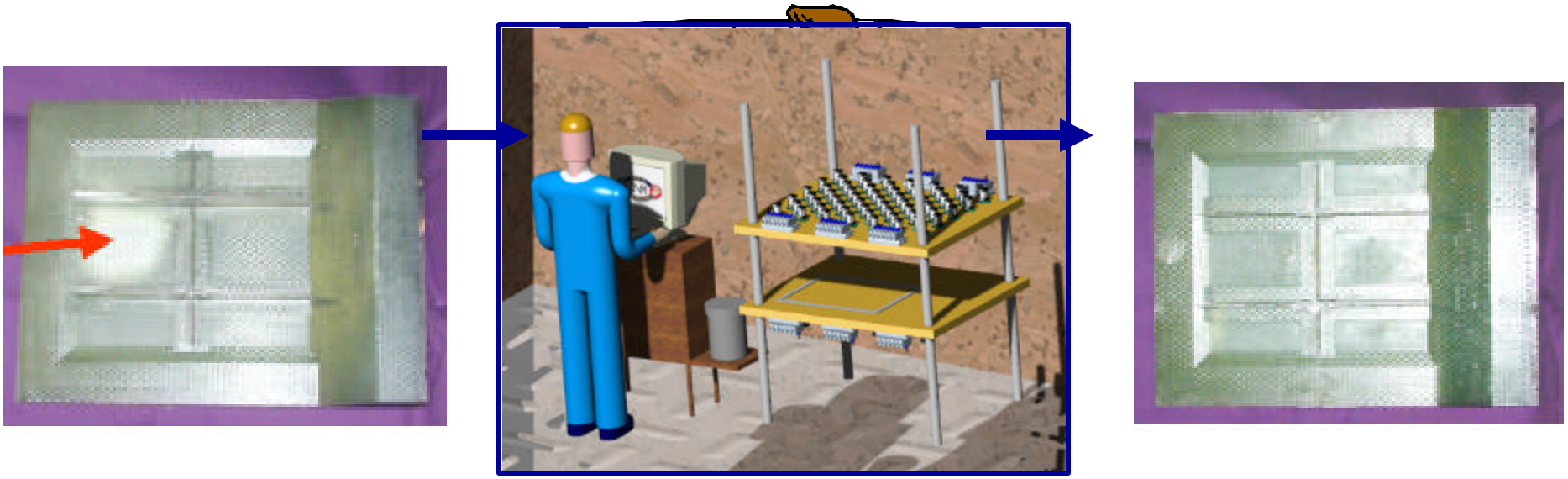
Motivation



There is a need to have better control of the filling stage to ensure part quality and increase yield of production.

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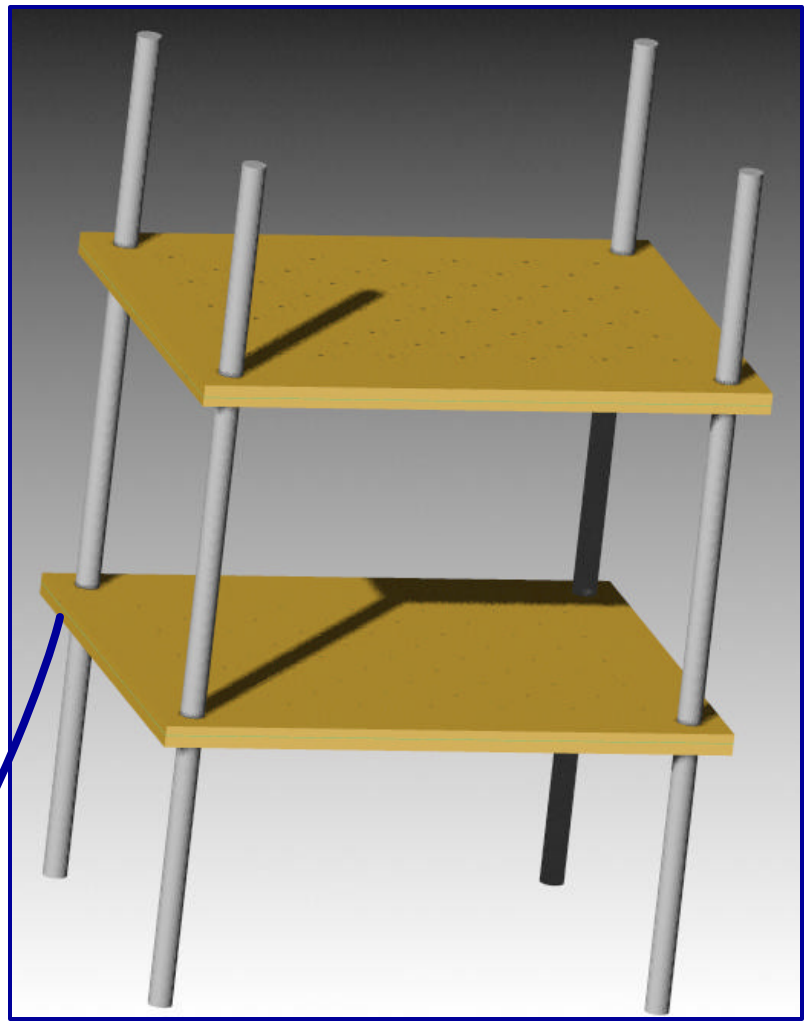
Mold Frame Work

The basic mold framework would consist of top and bottom plates, which can be opened and closed via a hydraulic system.



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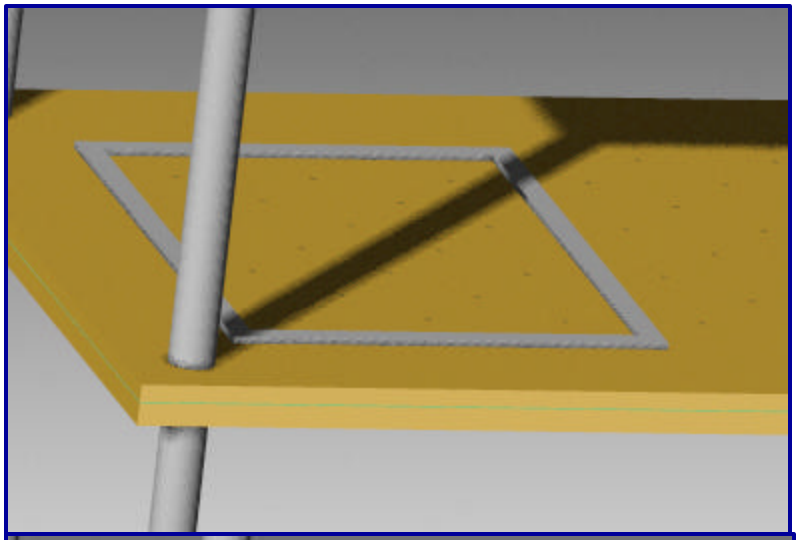
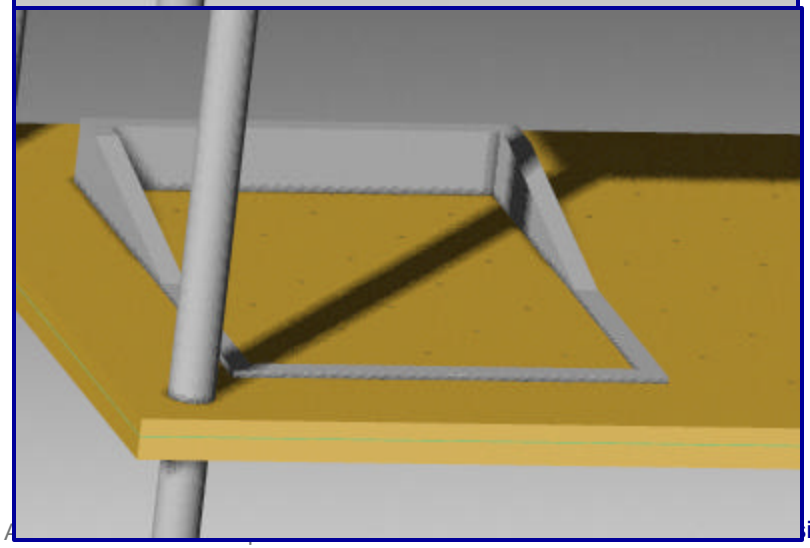
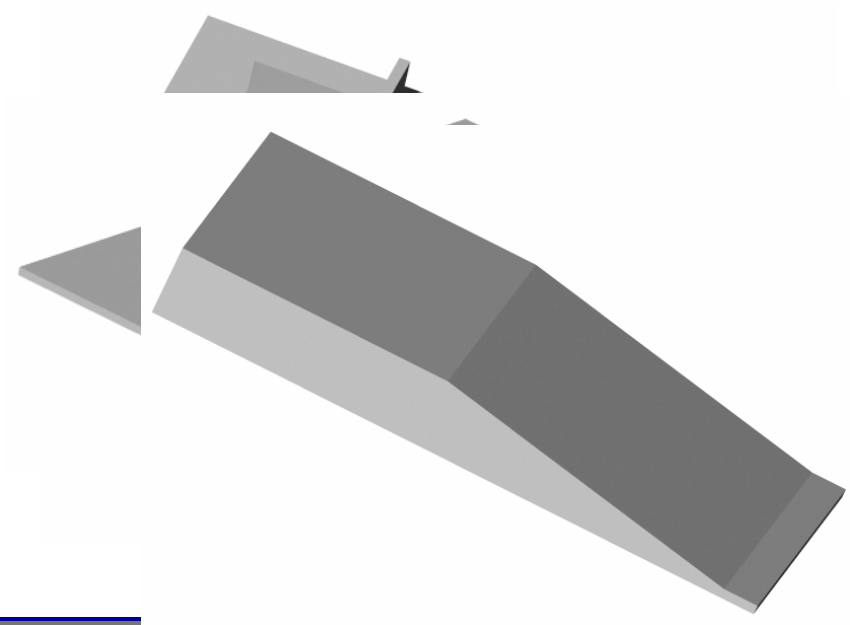
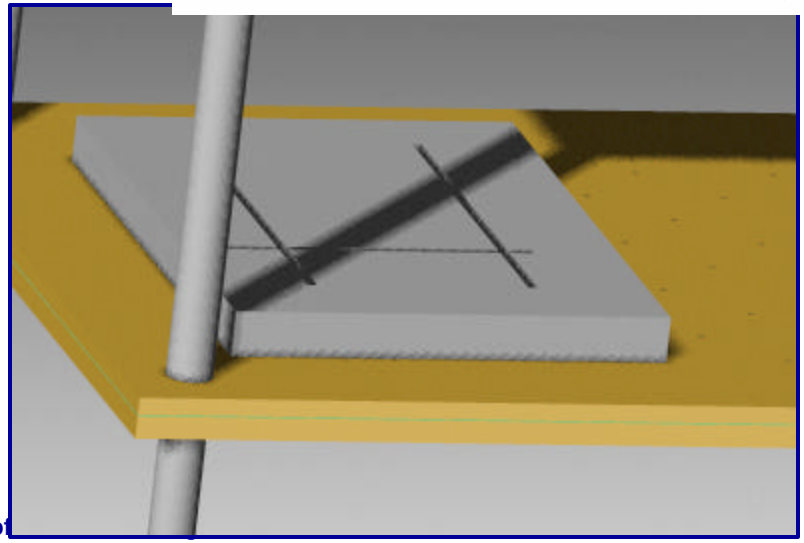
Modular Frame Work

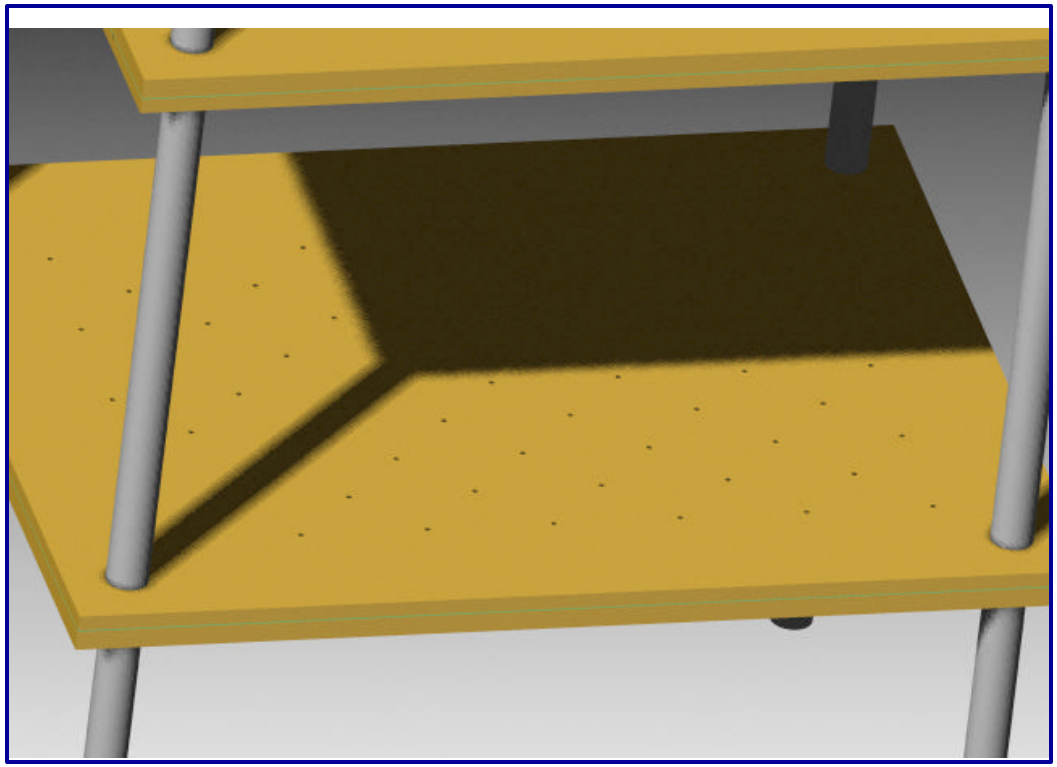








Multiple Injection System



Potential injection locations will be distributed all over the mold surface, to further accommodate various part geometries as well as provide the opportunity for flow control …

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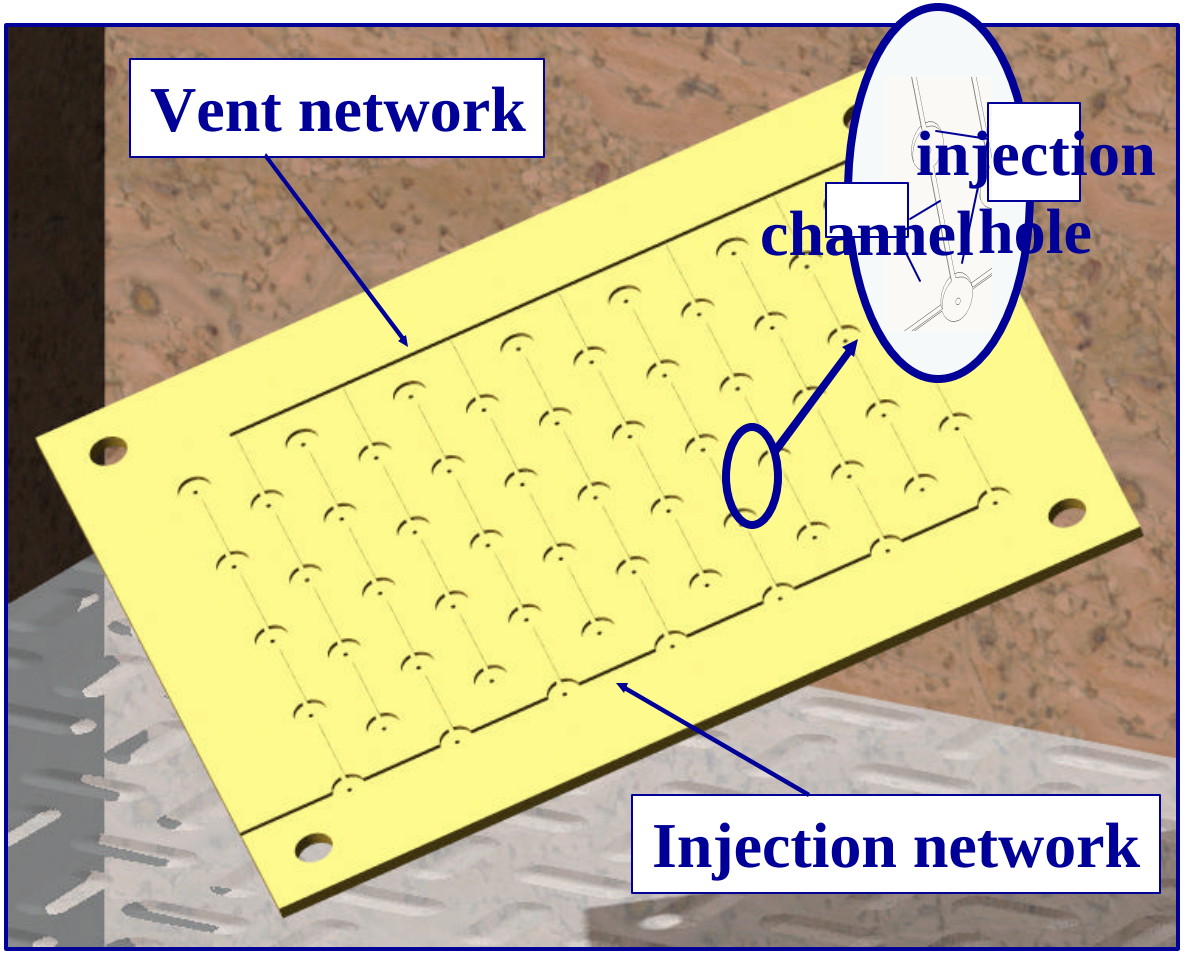
New Injection Method

A channel-based injection will eliminate the waste associated with the tubing



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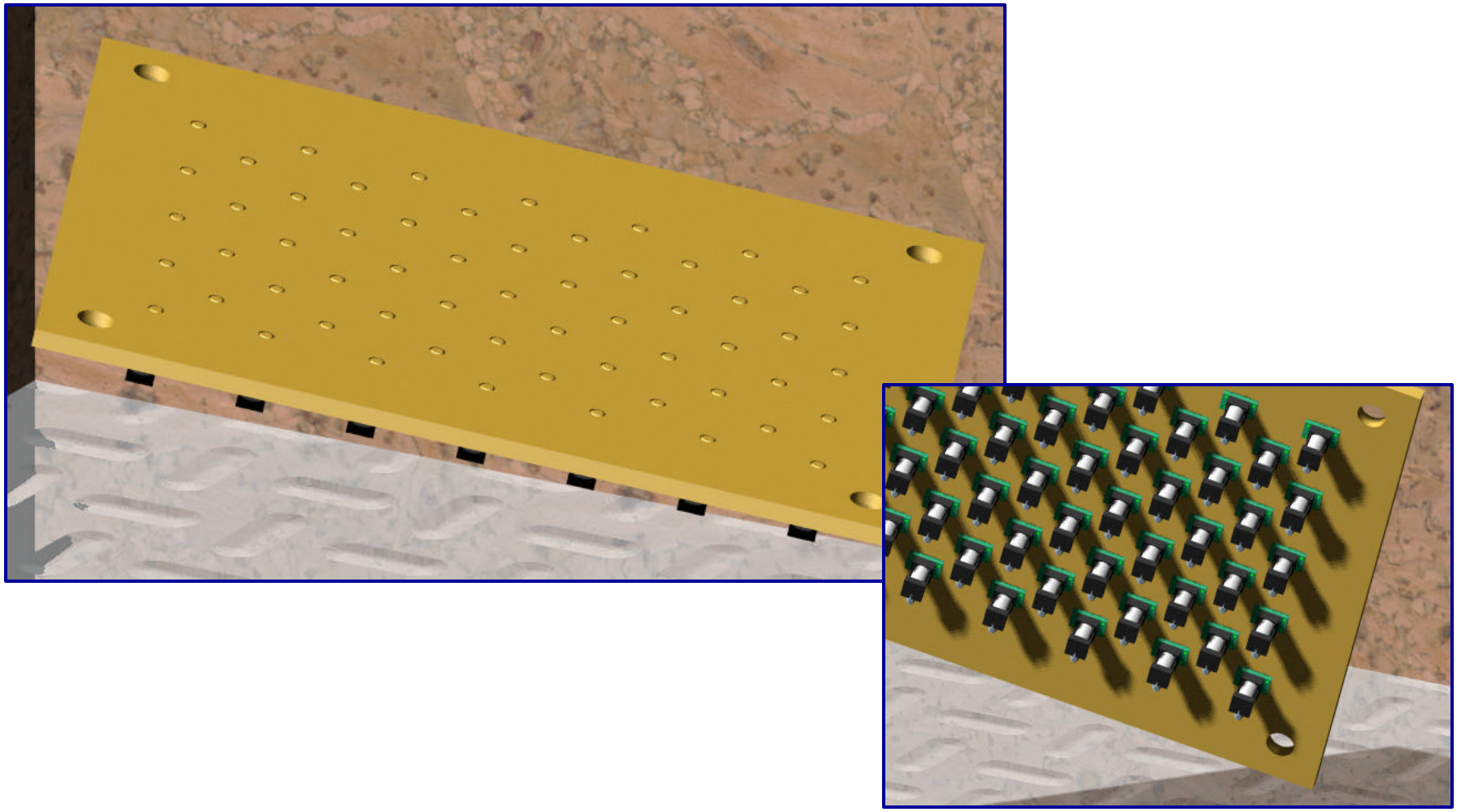
Piston System



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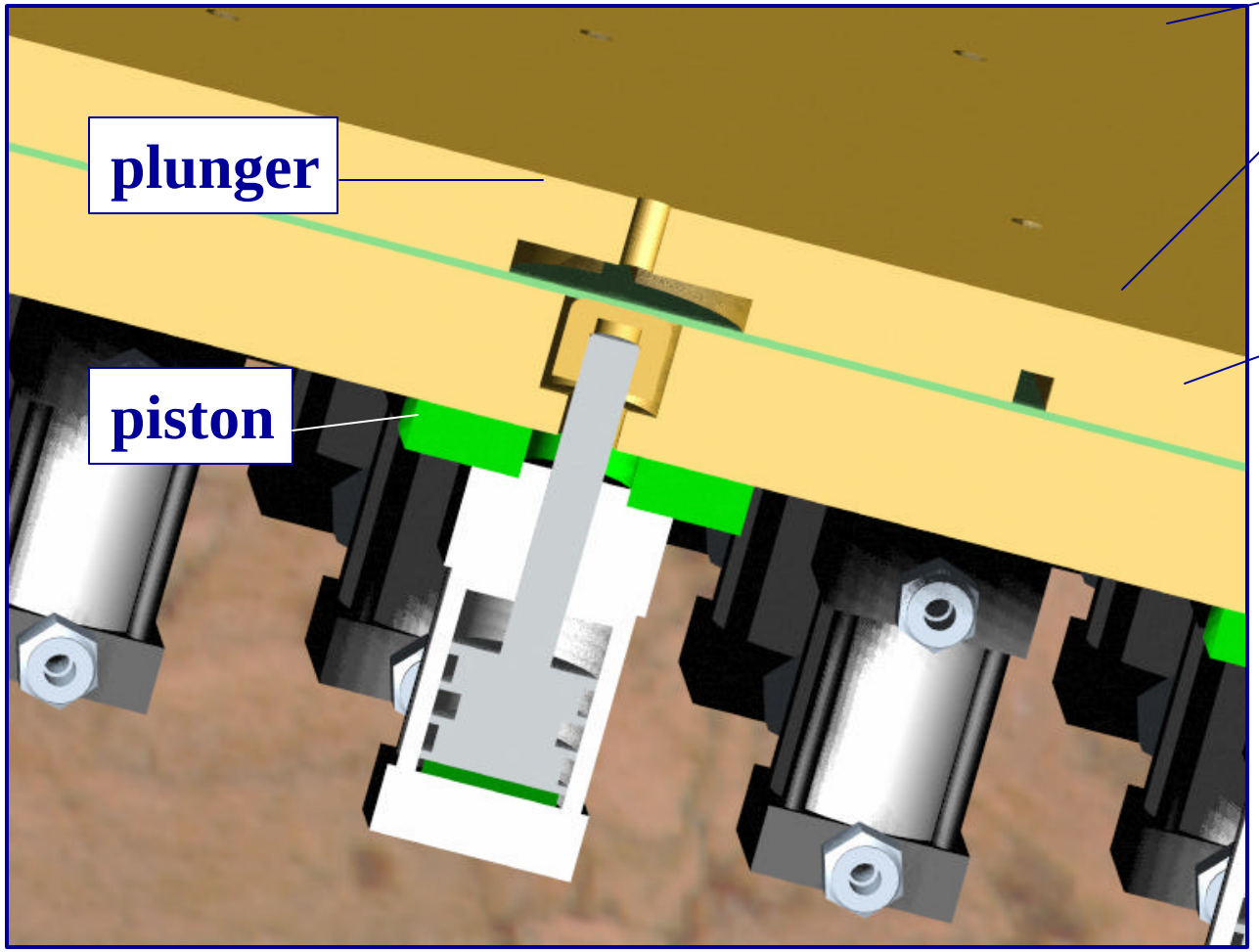
Details of the Piston System



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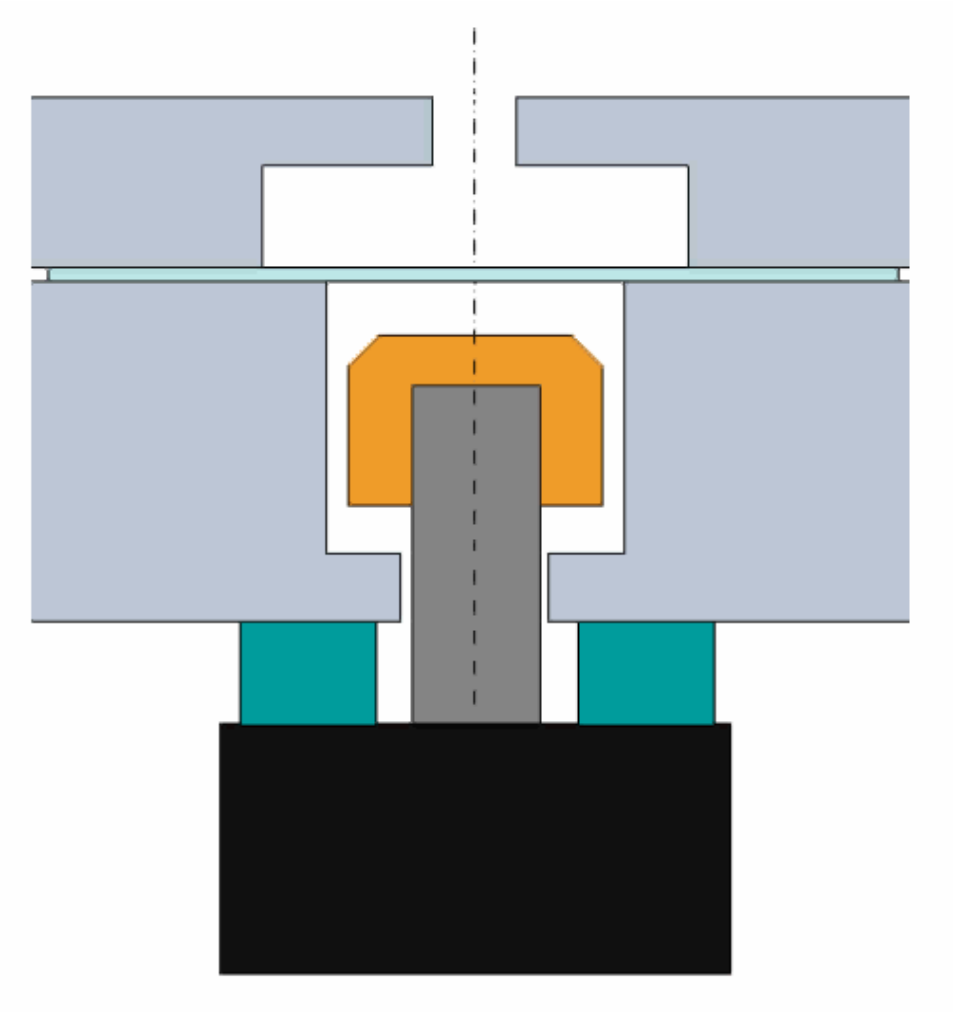
Schematic of Piston Operation: Open Position



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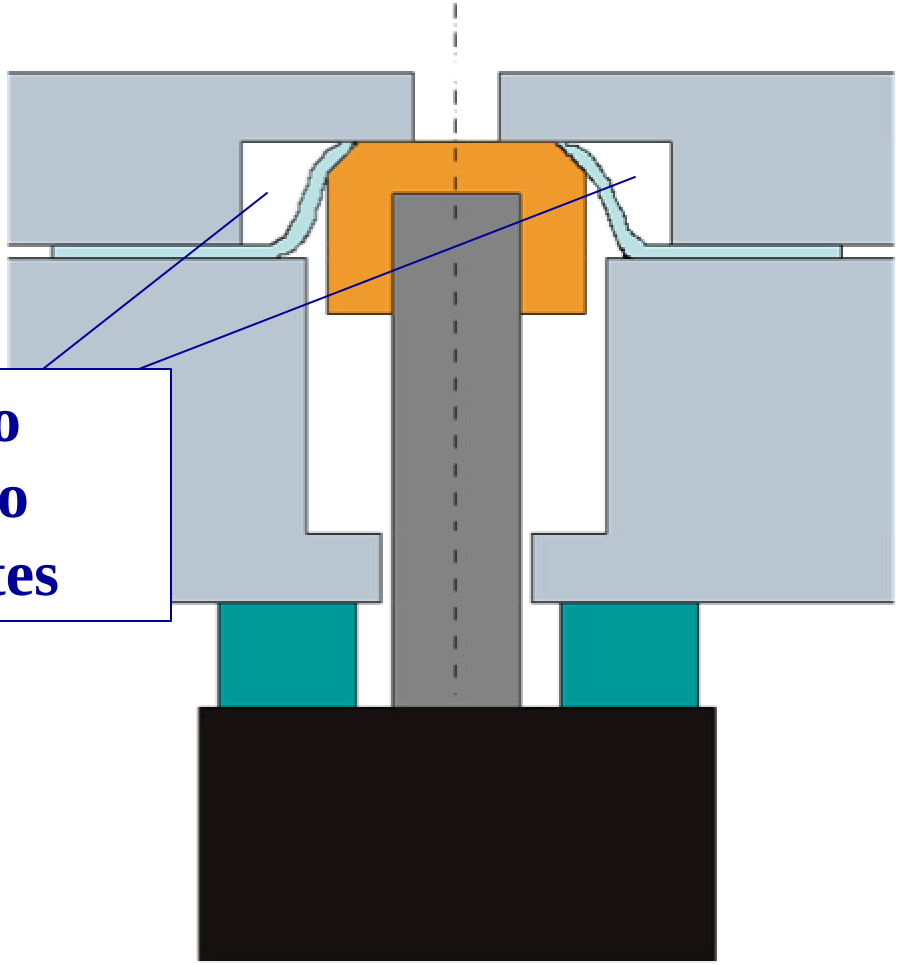
Schematic of Piston Operation: Closed Position



Area for resin to flow to deliver to downstream gates

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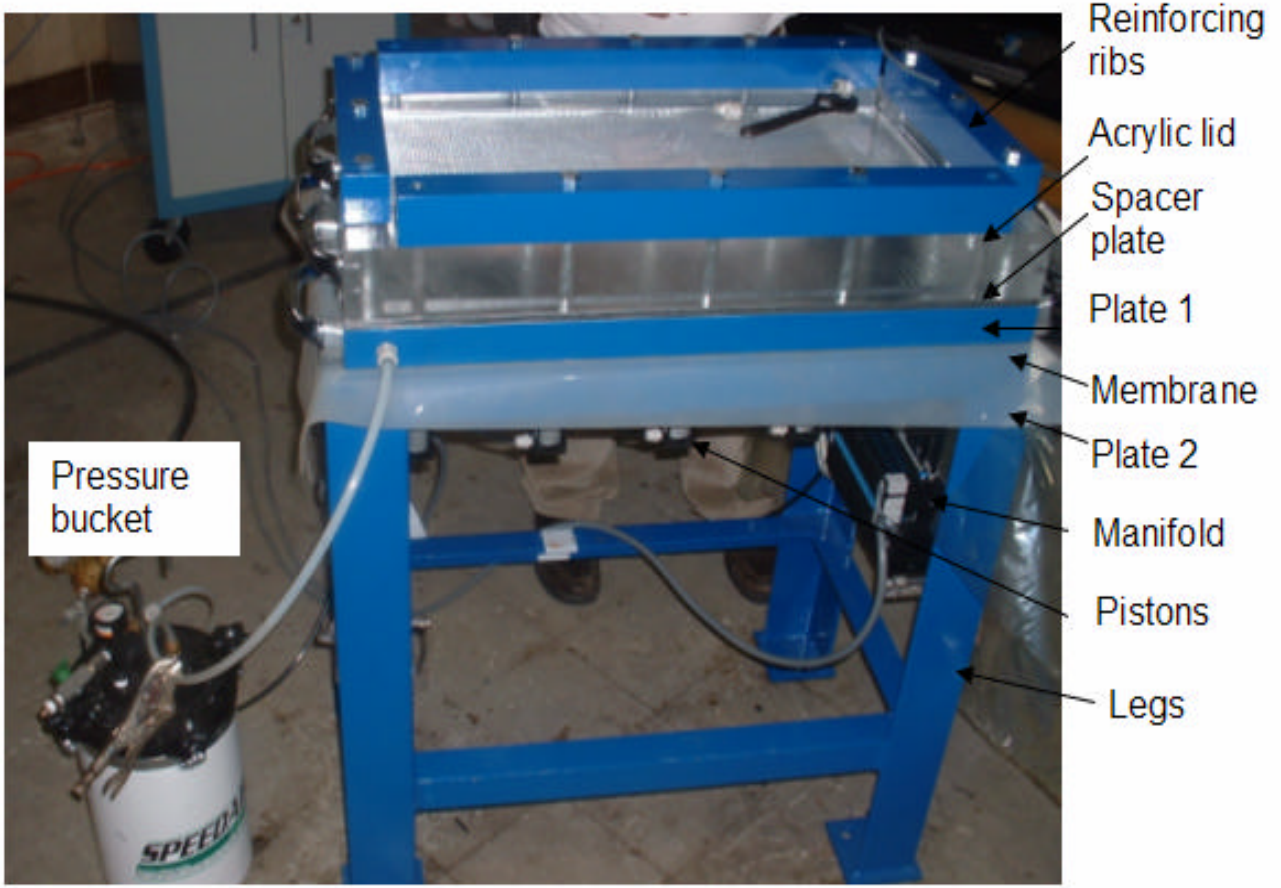
Fabrication and Testing of RTM Workstation



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Control Center – Neatly Containing All Data Acquisition Components

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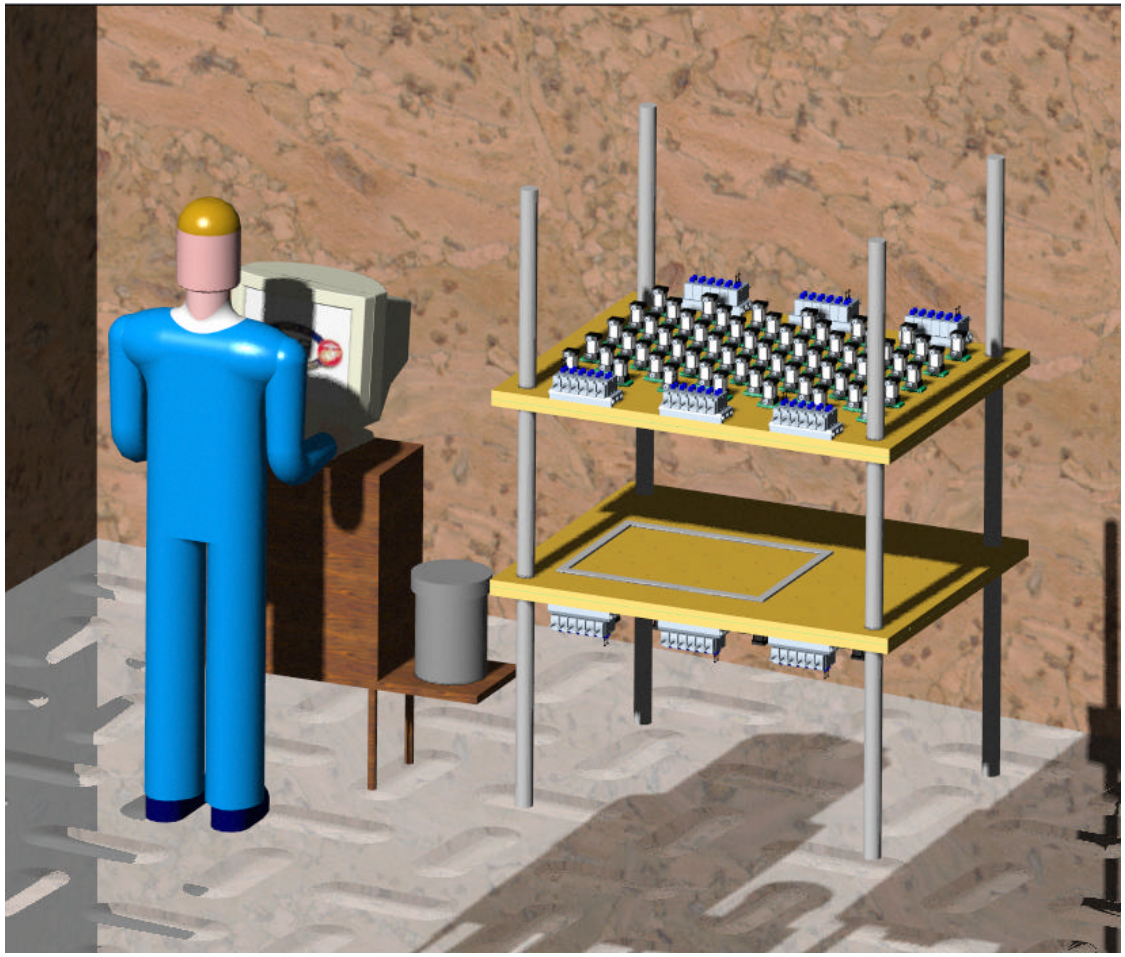
First Step in the Manufacturing Cycle

The mold system is ready to start with the first part



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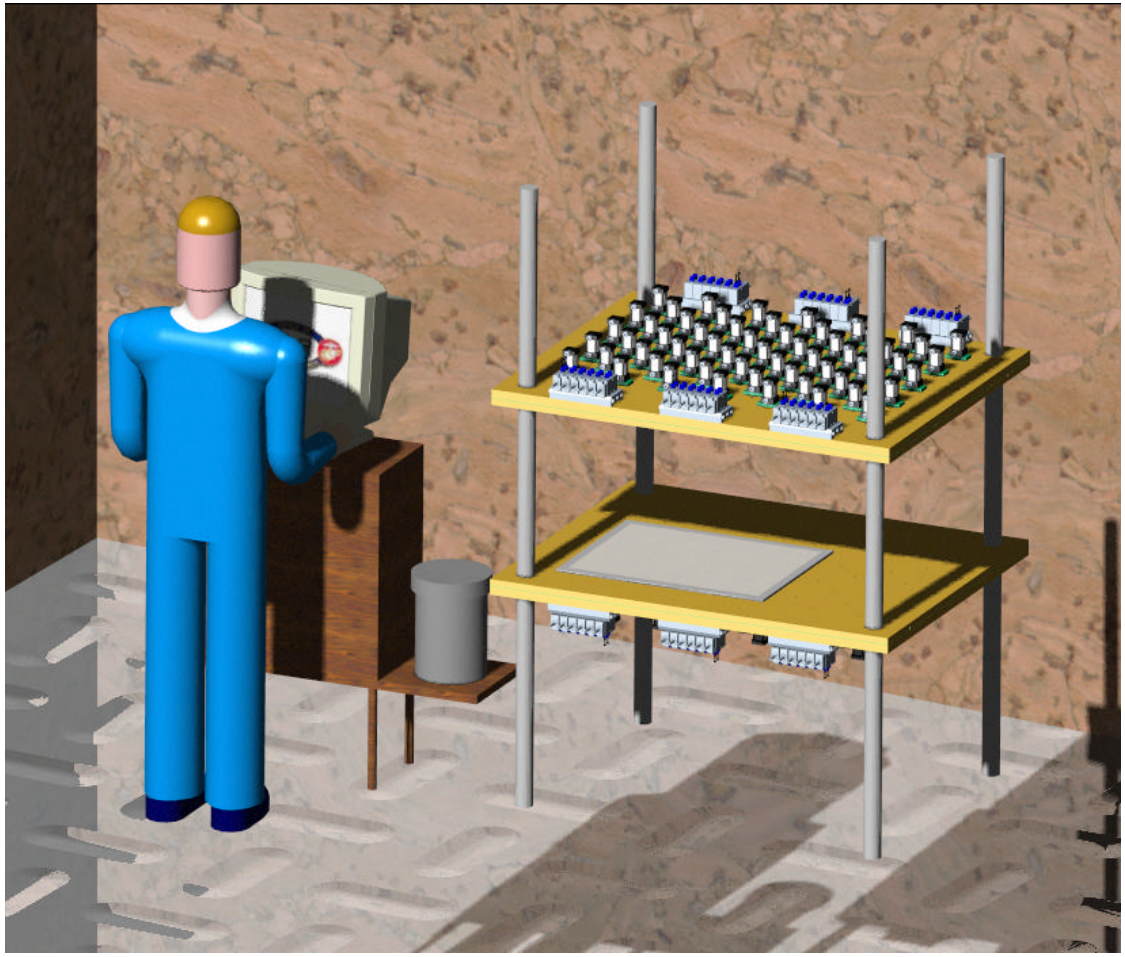
Next Step

The preform is loaded into the mold



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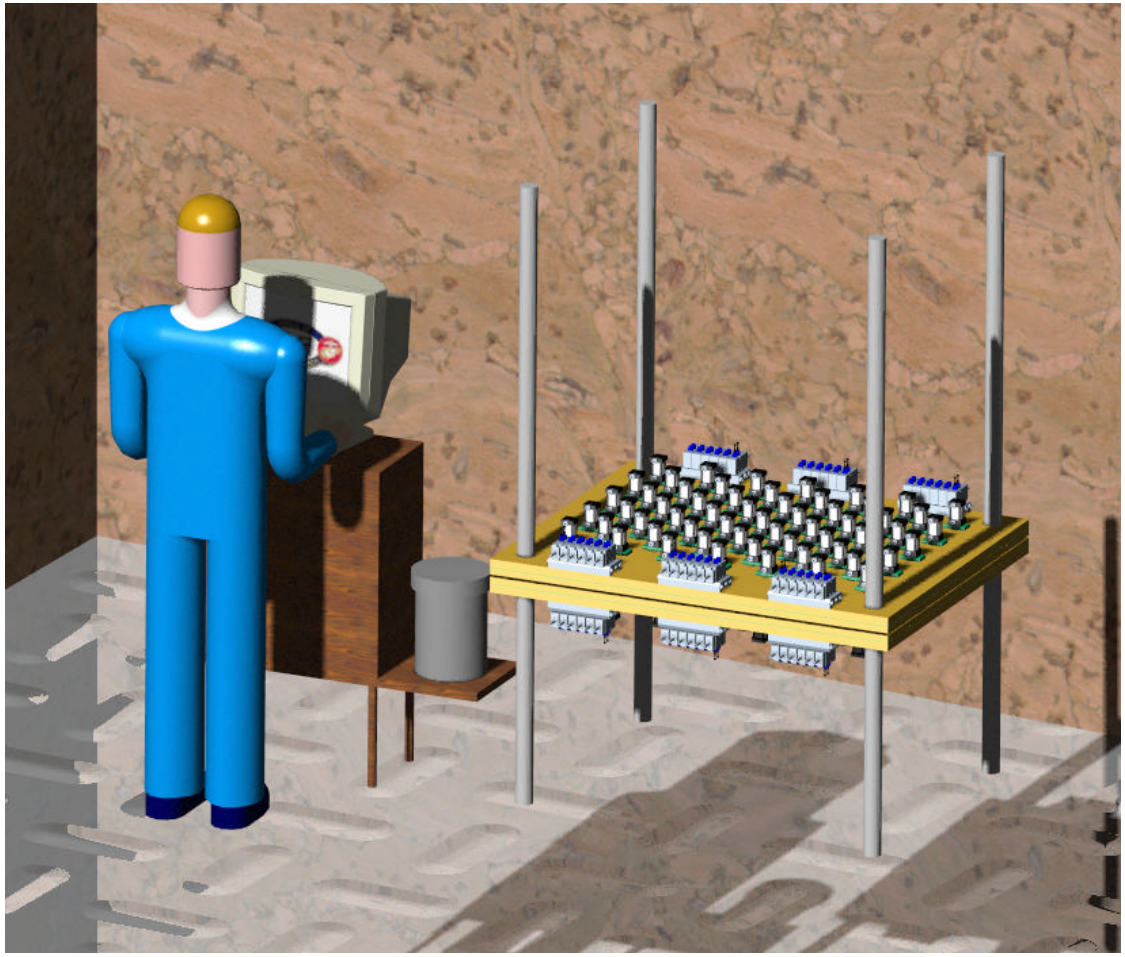
Next Step

The mold is closed and sealed, the resin is injected and allowed to cure



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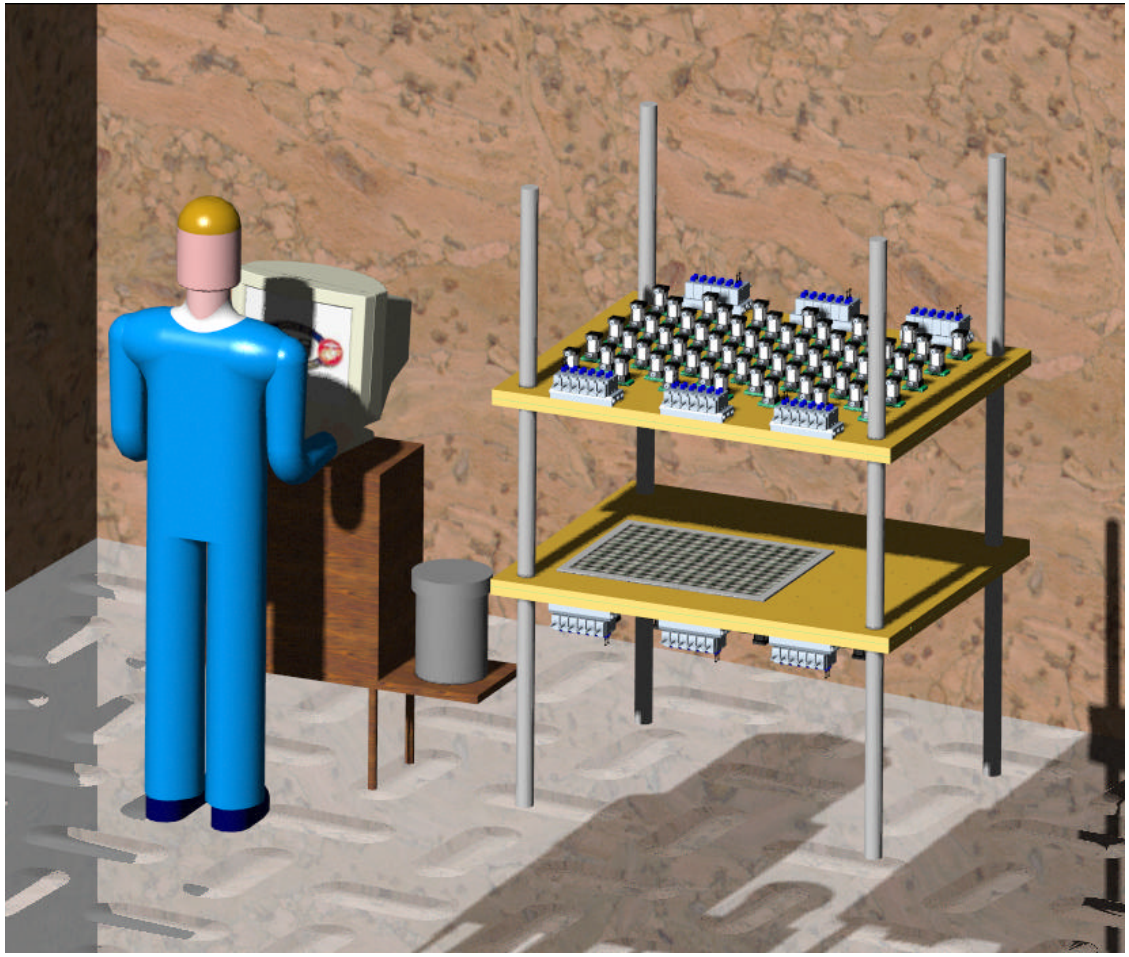
Next Step

The mold is open, revealing the filled part



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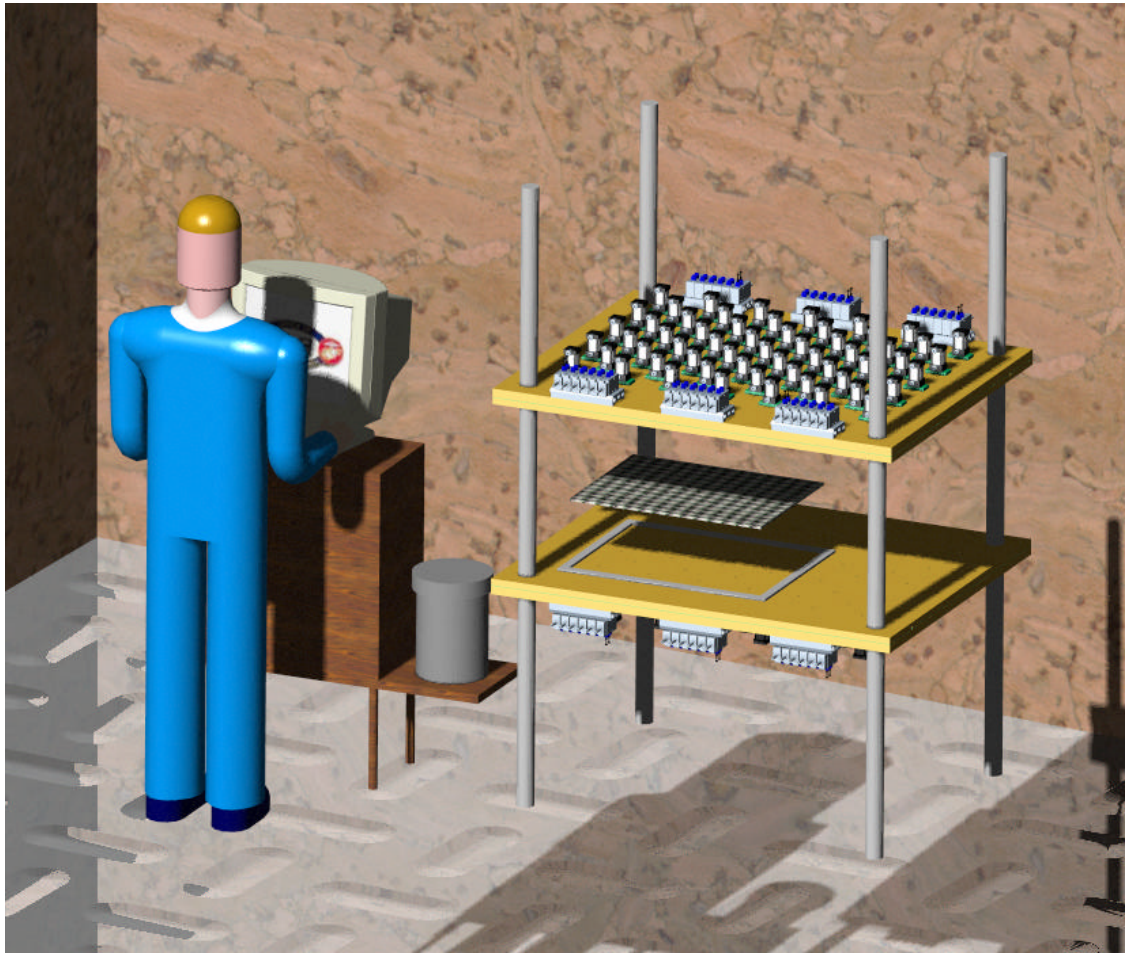
Next Step

The part is demolded …



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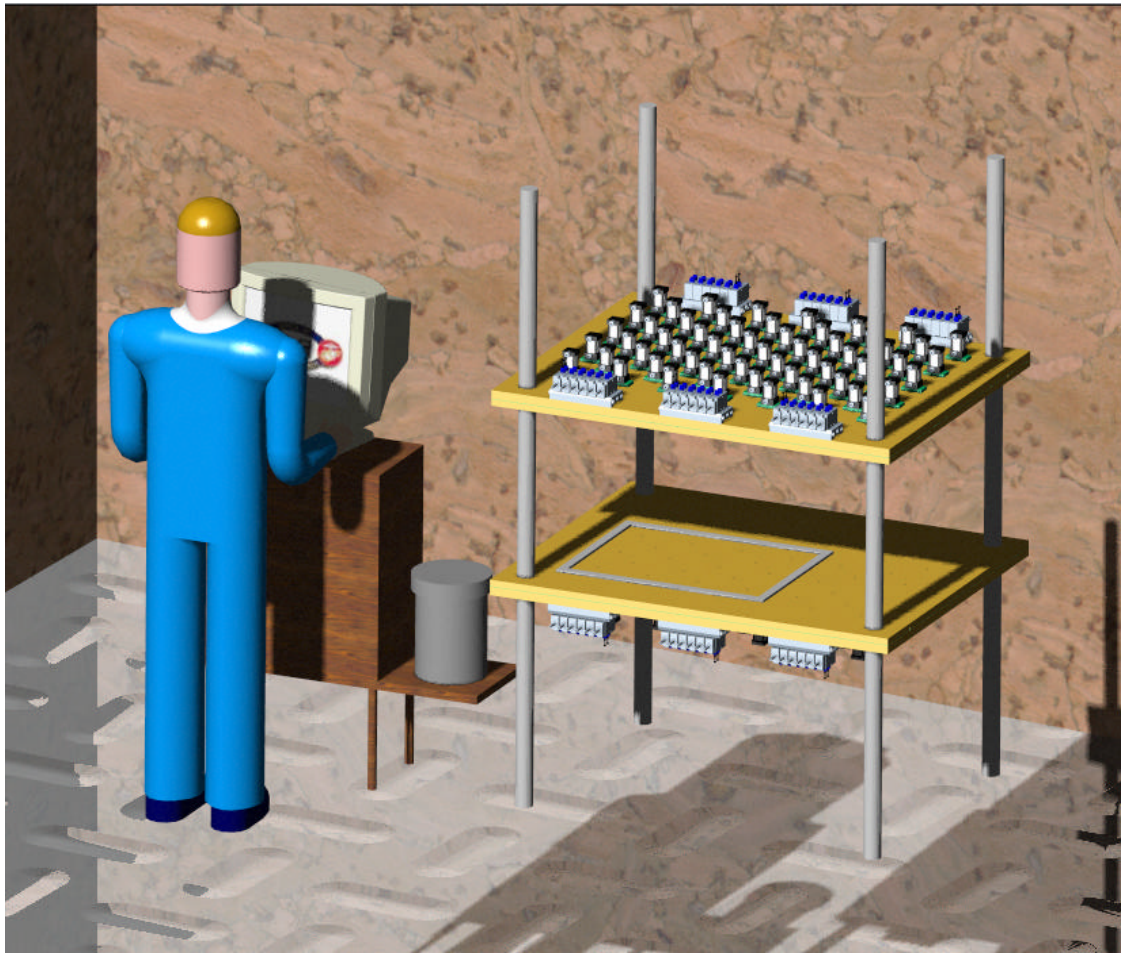
Next Step

… and removed from the mold



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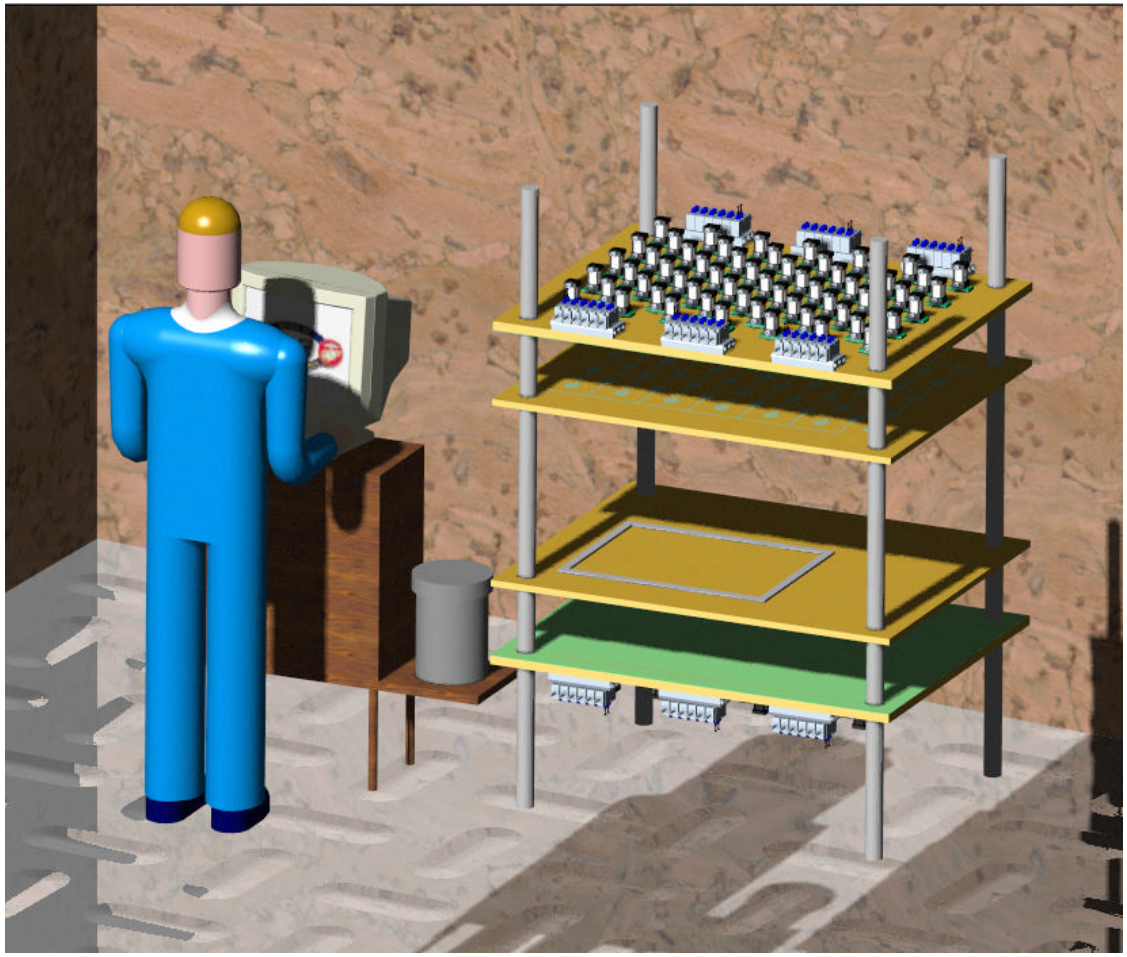
Next Step

The plate systems are separated revealing the resin chunks



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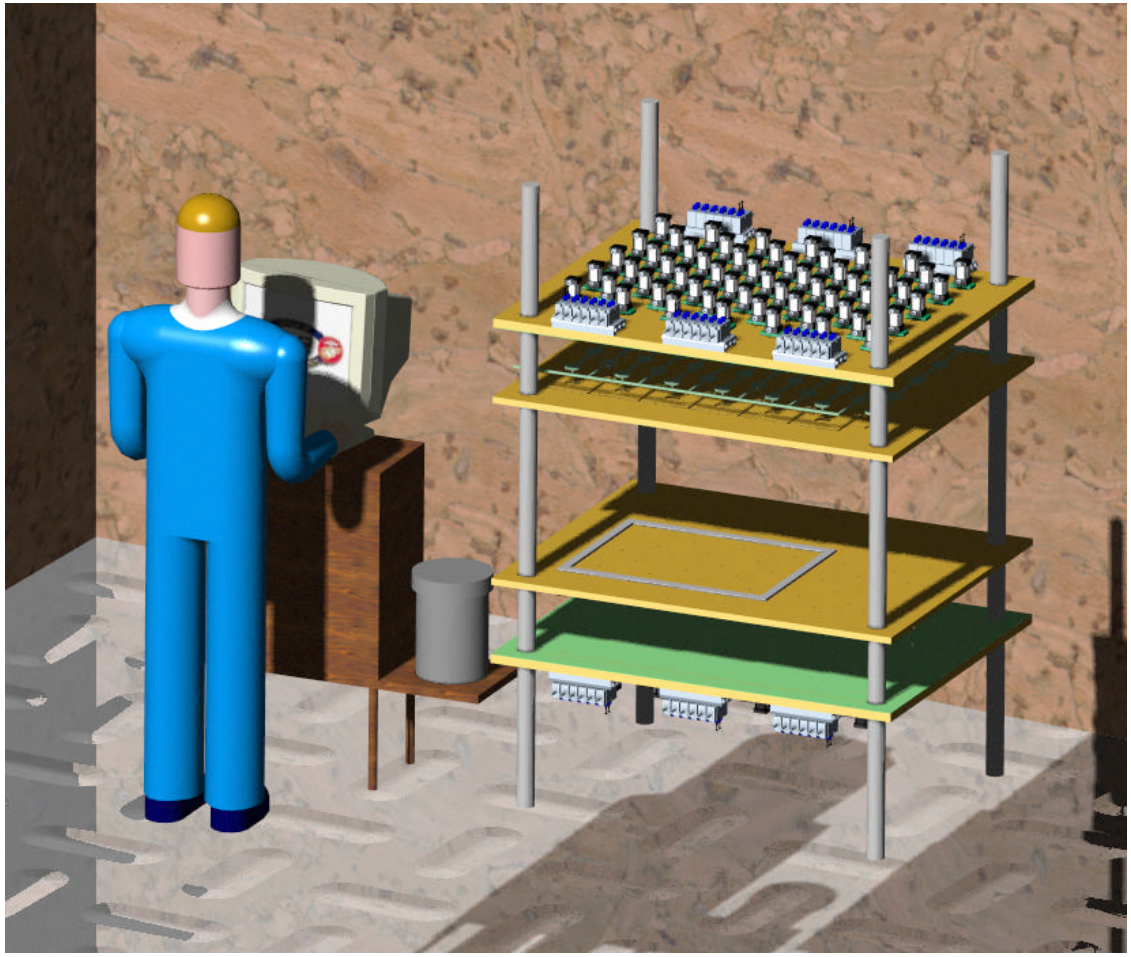
Next Step

The resin chunks are demolded …



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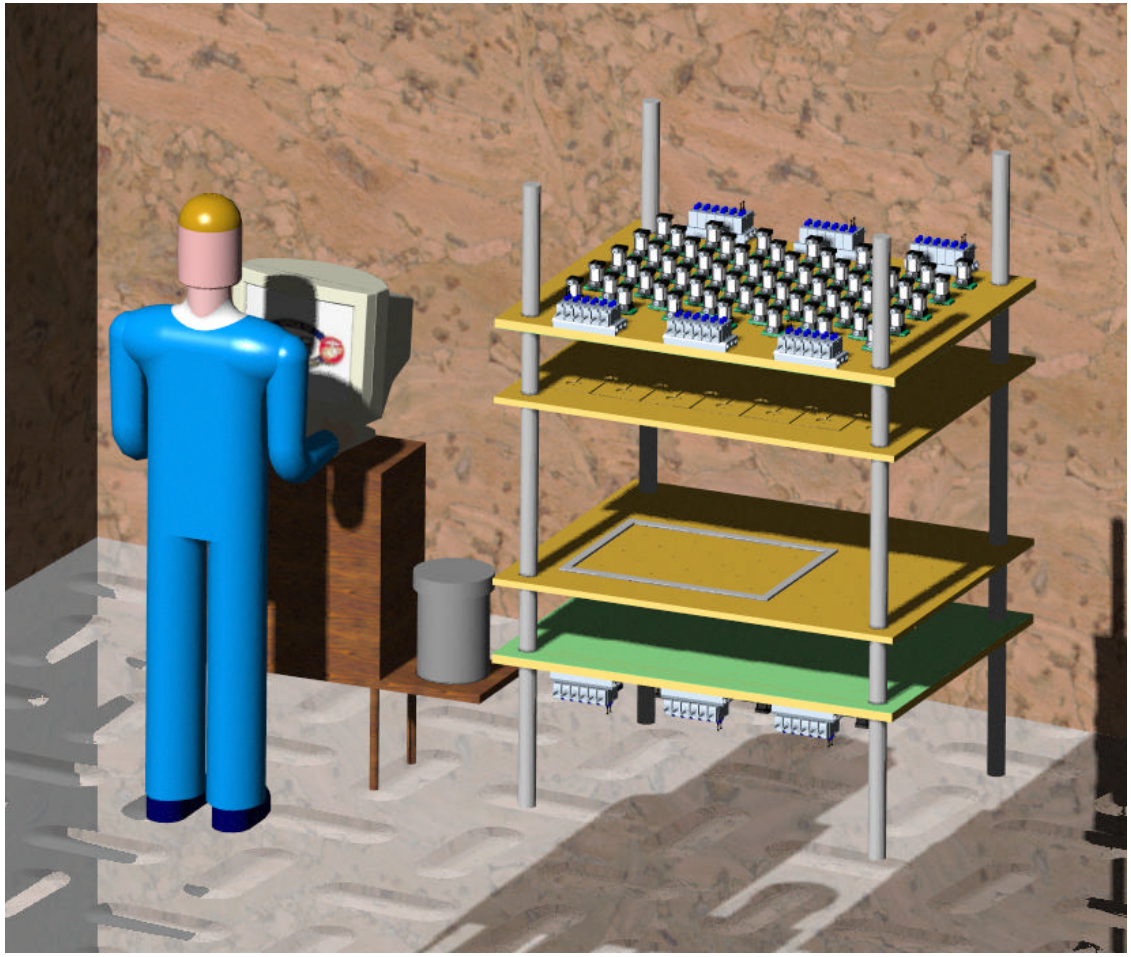
Next Step

… and removed from the mold



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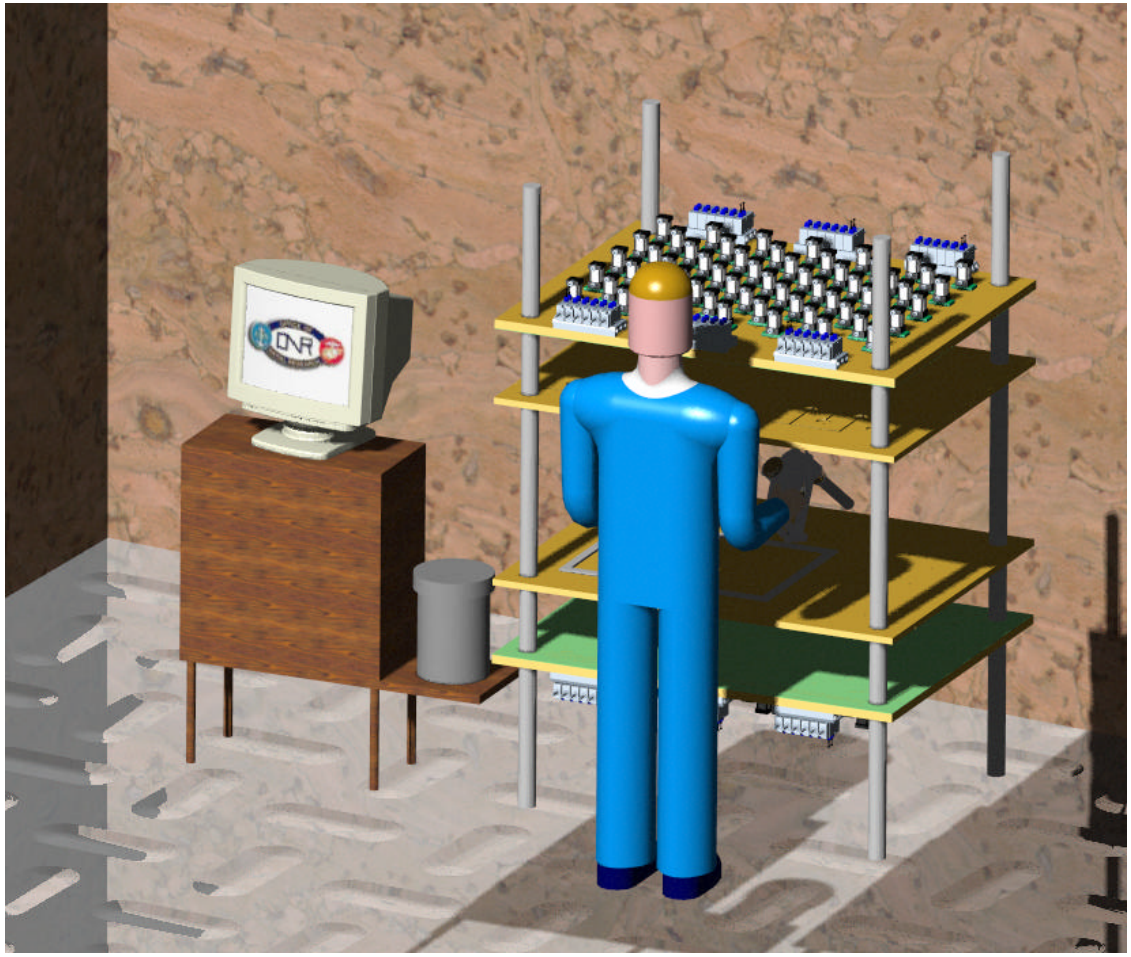
Final Step

Finally, the mold is prepared for the next part by applying release agent



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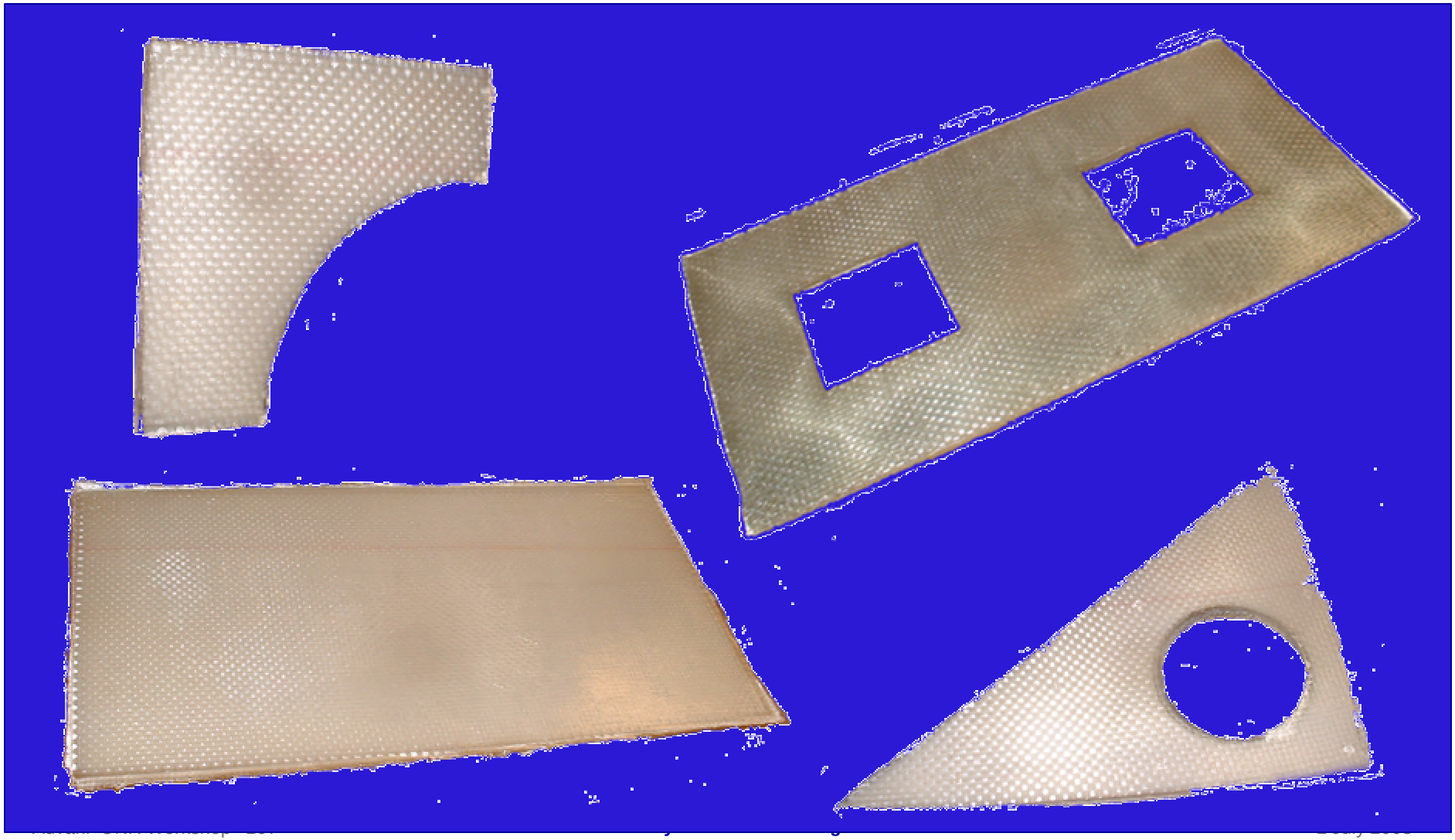
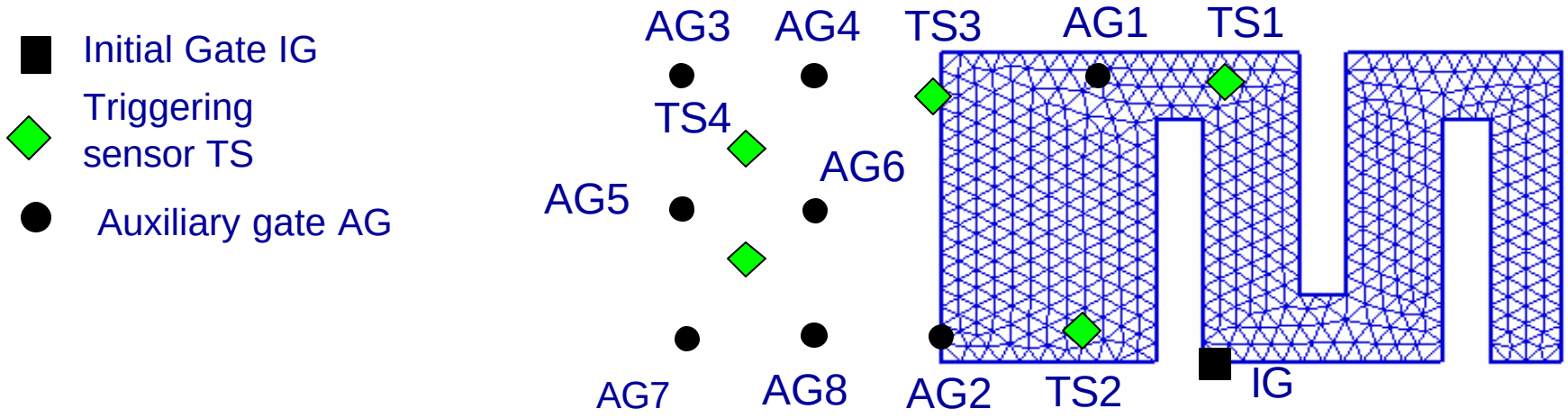
Versatility in Parts Manufactured



Validation Experiment



Step-2: Flow reaches TS1, which triggers automatically opening of AG1 and closing IG

Step-4: Flow reaches TS3, which triggers automatically opening of AG3,4,5,6,7,8

Step-1: Initial gate opens

Step-3: Flow reaches TS2, which triggers automatically opening of AG2

Step-5:Flow reaches TS4,5, which triggers vent closing.

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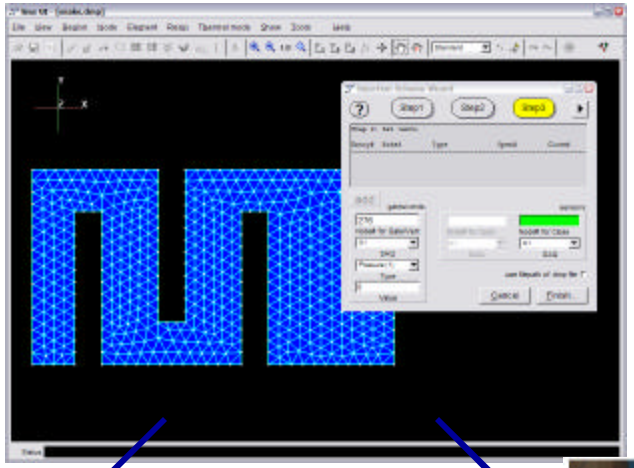
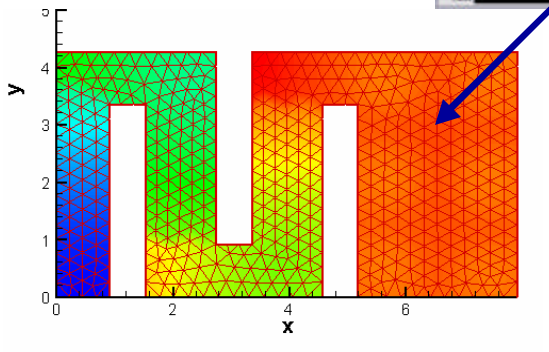
Sequential Injection Wizard





Simulation

Implementation fully automated

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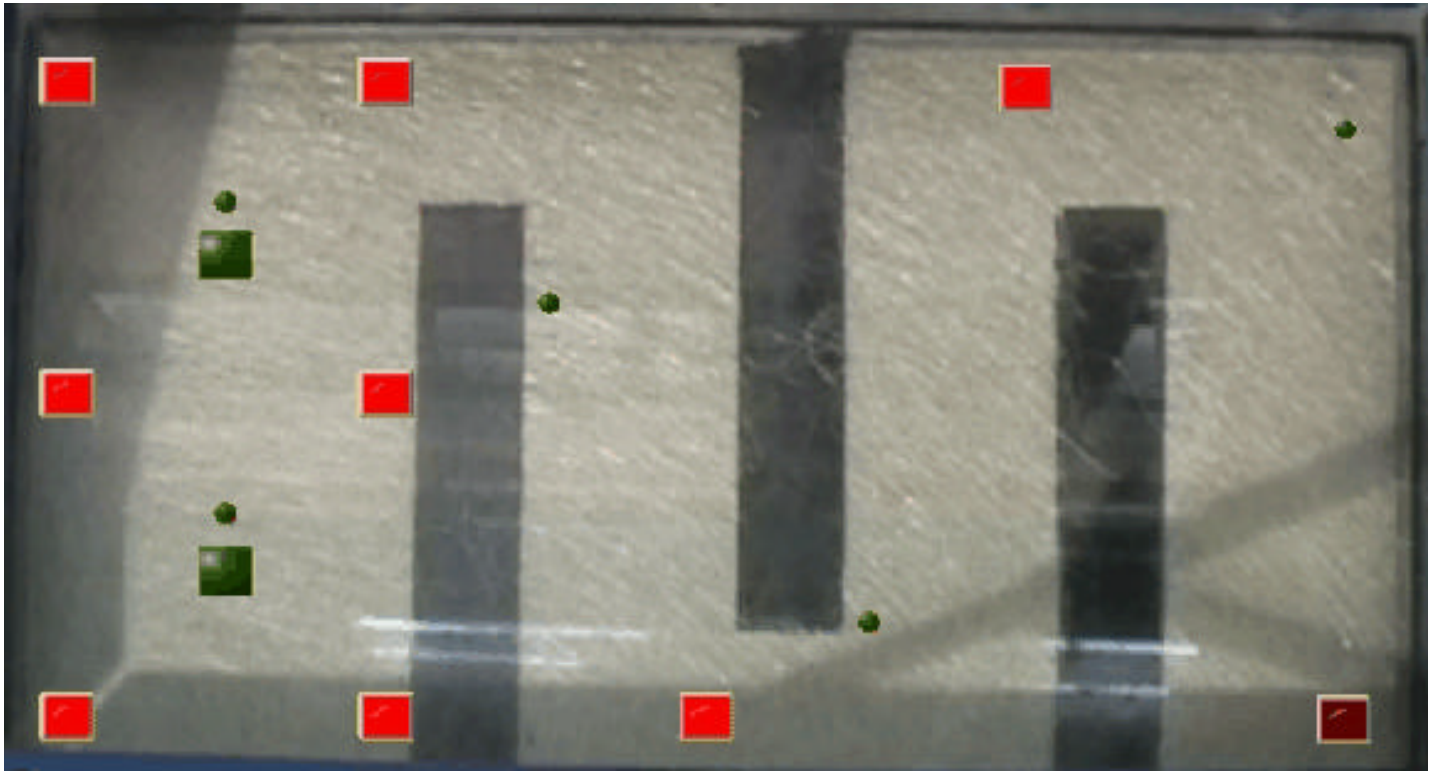
Sequential Injection Simulation



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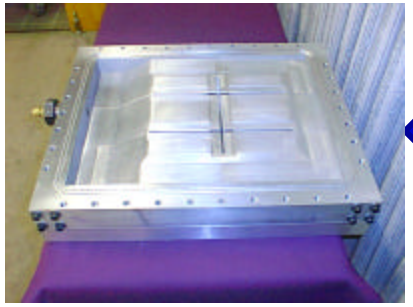
Roadmap to Automation in Liquid Molding

Design Mold and Location of Gates,Vents,Sensors

Develop Strategic Controller

Implement Active Control

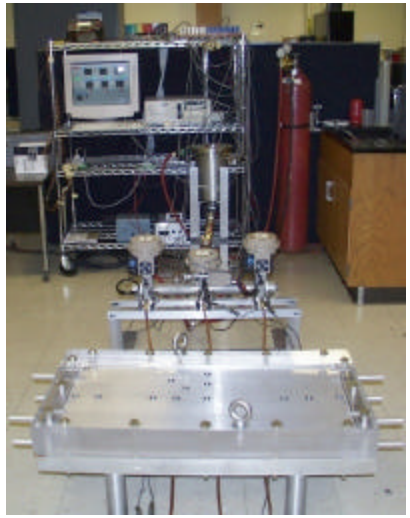


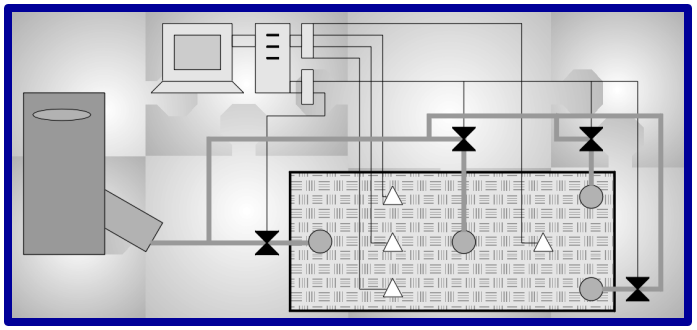
Scenario 1	Gate	Flow	Psi	Temp
Event 1	1000	3.5	80	70
Event 2	1100	3.0	90	70
Event 3	1010	2.5	70	70
...				
Event n	0001	1.5	30	75

Scenario 2	Gate	Flow	Psi	Temp
				70
				75
				75
				65
				80

Scenario 3	Gate	Flow	Psi	Temp
				65
				65
				65

Scenario N	Gate	Flow	Psi	Temp





Blueprint of Automation

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